

of a vast amount of energy stored in a sheared filament. But the details of that particular flux emergence are subtle (Harvey 1983); it is by no means clear how the interaction between the filament and emerging flux should be conceived when the adjacent net photospheric flux decreases during the emergence. The experience with the 1980 June 25 flare, where adjacent emergent flux could not be found, should caution us that the flare triggering process is still elusive.

1.3.5.3 Summary and Recommendations for Studies of Emerging Flux

The vigorous advance of theory (Priest 1984a, 1984b) has brought into sharp focus the observational requirements to test the Emerging Flux Model. From an observational perspective, however, even the conceptual role of emerging flux in the flare process is clouded. Growth of magnetic flux is a necessary pre-condition for flares: small flares are common during the AFS stage of an active region: large flares often have their initial kernels rooted in new, rapidly growing flux. But the vast bulk of magnetic flux appears at the surface without producing flares as strong as a M1 event in X-rays. The published cases of flare-associated filament eruptions lack key facts which are needed either to validate the reconnection inherent in the Emerging Flux Model or to constrain the model in terms of our understanding of flux emergence in the absence of flares. One study of a flare-associated filament eruption on 1980 June 25, observed in detail for many hours at heights in the photosphere, chromosphere, transition zone and corona, rules out local emerging flux as either a driver or a trigger of the activation of that particular flare.

An important new result is the association of Cancelling Magnetic Features with Flares (Martin, 1984). These may have a similar role to emerging flux in triggering flares (Priest, 1985), since what is important is the *interaction* of flux, whether through material vertical or horizontal motions.

A major advance towards clarifying this situation would come from coronal observations aimed specifically at the problem of emerging flux. Jackson and Sheridan (1979) found general increases in activity of Type III radio bursts prior to flares, which imply that energy, originating in the emergence of new flux, is entering the corona on a time scale of many hours. We badly need to supplement the detailed chromospheric and photospheric observations of emerging flux, now available, with simultaneous multi-wavelength coronal observations of comparable spatial resolution ($\approx 1''$) and comparable duration (many hours, even days, preceding the emergence). Target regions of emerging flux need to be followed long enough at all levels of the atmosphere to come to grips with the formation of AFS and field-transition arches, and in contrasting emergences of flux accompanied by their well-established signatures from simple appearances of new flux without those signatures. More than semantics are at stake; our concepts of the magnetic inter-

connections in the latter situation are woefully inadequate. Finally, we need to clarify the association between ephemeral regions and coronal bright points on an individual basis. In so doing, we should gain insight into the dissipative mechanisms which seem to occur with great frequency on a basic scale, and which might be applicable to ordinary flares.

1.4 CORONAL MANIFESTATIONS OF PREFLARE ACTIVITY

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1.4.1 Introduction

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Recent observations confirm the view that the initial release of flare energy occurs in the corona, with subsequent emissions arising from the interchange of mass and energy between different levels of the solar atmosphere. Knowledge of coronal preflare conditions is essential to understanding how energy is stored and then released in flares. Observational evidence for storage is, however, difficult to interpret owing to our inability to observe the three dimensional structure of the magnetic field and to the lack of coordinated observations with high resolution in space and in time.

More than sufficient energy to power flares can be stored in local magnetic fields on time-scales of hours. Long-term changes include emerging and evolving magnetic flux regions, satellite sunspots, sunspot motions, and velocity patterns (Martin, 1980; Section 1.3 these proceedings). Although such evolutionary changes are considered necessary for the storage of energy leading to especially large flares, it is very difficult to relate specific long-term changes to particular flares since similar changes occur in their absence.

More rapid changes can occur within minutes or a few hours preceding a flare, and they can be more unambiguously interpreted as flare precursors. Clearly, this distinction is arbitrary, but it does provide a useful operational definition of preflare patterns. These more rapid changes, especially in the corona, were the subject of the third subgroup of the Preflare Activity Team.

1.4.1.1 Review of Previous Studies of Coronal Precursors

Earlier searches for rapid flare precursors involving coronal phenomena recognized the physical importance of the corona for storage and release of flare energy. Reported coronal precursors have included X-ray brightenings associated with filament activations (Rust *et al.*, 1975), expanding and brightening green-line arches (Bruzek and DeMastus, 1970), gradual enhancements and spectral hardening of soft X-ray and microwave flux (Webb, 1983), "forerunners" of white-light transients (Jackson and Hildner, 1978), changes

in circular polarization and intensity at centimeter wavelengths (Lang, 1974; Kundu *et al.*, 1982; Willson, 1983), pre-burst activity at 1.8 cm (Kai *et al.*, 1983) and preflare type III burst activity at meter wavelengths (Jackson and Sheridan, 1979).

Filament activations and associated manifestations, which are frequently observed with two-ribbon flares, have been the most readily observed and most studied forms of rapid flare precursors (Smith and Ramsey, 1964; Martin and Ramsey, 1972). The enhanced darkenings, organized motions and reconfigurations which constitute an "activation" were summarized by Smith and Ramsey (1964) and more recently by Martin (1980). The prevalence of the phenomenon is evident in the statistic (Martin and Ramsey, 1972) from a sample of 297 flares (importance > Class 1) that about half the flares in that sample exhibited preflare filament activity. Prior to or during a filament activation, changes in certain photospheric and chromospheric structures occur, which have been taken as evidence of evolving or emerging magnetic flux (e.g., Rust, 1976).

Preflare observations in soft X-rays have been used in a number of studies. Culhane and Phillips (1970) observed 7 precursor events at 1-12 Å, one occurring 15 min before flare onset, using an OSO-4 full-sun detector. Thomas and Teske (1971) performed a statistical study using a full-sun detector on OSO-3 and found a tendency for the onsets of X-ray events to precede those reported in H α . For a small number of events Roy and Tang (1975) found specific enhancements in full-sun X-ray flux to be associated with different stages of preflare filament activity.

With better spatial resolution (20 arc-sec) Rust *et al.* (1975) identified OSO-7 EUV and soft X-ray enhancements with a filament activation 30 minutes before flare onset. Van Hoven *et al.* (1980) studied the preflare phase of a set of 12 flares observed by the same OSO-7 detectors with one-minute time resolution. Eight of the 12 showed definite enhancements in both X-ray and EUV 2-20 min prior to the onset. Interestingly, in 6 of these 8 cases the enhancements were observed simultaneously in both cool He II and hot Fe XXIV lines. Although the Skylab experiments had excellent spatial resolution (arc-sec), the operational modes limited the availability of preflare data to a few specific observations of EUV and soft X-ray precursors (see Van Hoven 1980 for details). Petrasso *et al.* (1975) and Levine (1978) observed pre-existing coronal loops to brighten 5-10 min before they flared. The XREA full-sun X-ray detector typically detected preflare enhancements 2-20 min before the impulsive phase. There was evidence for slight temperature increases in these events, and an increasing tendency for large flares to have associated precursors.

In more comprehensive, statistical studies, Vorpahl *et al.* (1975) found many cases where X-rays from the flare regions were enhanced prior to onset, but Kahler and Buratti (1976) and Kahler (1979) found that there were no systematic

preflare X-ray brightenings at the locations of subsequent small flares, and therefore no requirement for coronal preflare heating of the flare loops. However, coronal preflare brightenings were observed in the Skylab X-ray data in areas of the active region adjacent to the flare site.

Recently, Webb (1983) studied similar sets of the AS&E Skylab X-ray data with the goal of determining whether X-ray precursors systematically occurred within the flare active region and what their characteristics were. The study differentiated between observations relating to the preheating of flare structures, and precursors which might have time and spatial scales and locations different from that of the flare. High time-resolution H α and daily photospheric magnetograms were also used. A majority of the flares studied had preflare X-ray features, but typically not at the flare site, occurring within 30 minutes prior to onset. The X-ray precursors consisted of one to three brightened loops or kernels per interval, with H α emission at the feet of the loops or cospatial with kernels. Electron pressures of a few dyne cm⁻² were derived for several typical coronal features. In half of the cases the X-ray precursors were associated with preflare H α filament activity. The preflare and flare events occurred on or near the main active-region neutral line.

Using moderately resolved (arc-min) OSO-8 X-ray observations, Mosher and Acton (1980) and Wolfson (1982) reported no systematic enhancement in active regions in 20-minute intervals preceding flare onsets. But their detector was less sensitive to the lower energy, cooler precursors reported earlier from Skylab.

Radio observations provide important data on coronal emission and changing magnetic fields before flares. Individual observations of microwave preflare activity in the form of increased intensity and changing polarization have been reported in the past. With the increasing sensitivity and spatial resolution of such instruments as the VLA, these observations have become better defined, as discussed in Sections 1.4.2 and 1.4.5.

Green line (5303 Å) observations above the solar limb showed acceleration and expansion of coronal arches up to one hour before two flares (Bruzek and DeMastus 1970). Skylab observations of white light mass-ejection "forerunners" (Jackson and Hildner 1978) indicated that such activity might precede H α flare onset. Recent SMM results, together with improved metric radio and lower altitude K-coronameter data (Wagner 1982) support the overall picture that a large volume of the corona can become activated up to an hour or so before a flare.

1.4.1.2 Objectives

Our objectives in studying preflare coronal phenomena were threefold: to select a suitable data set, to determine appropriate physical parameters, and to search for associations among events so as to identify the relevant physics in preflare phenomena.

A wealth of new information about active regions and preflare activity is now available from the coordinated observations conducted during the Solar Maximum Year by the Solar Maximum Mission satellite, by other spacecraft, and by ground-based observatories. The wavelengths accessible to a study of the preflare coronal condition range from centimeter-wavelength microwaves to hard X-rays. Table 1.4.1 summarizes the data that were used in our study by wavelength and instrument, and the references to publications of events covered in this report. Previous multi-wavelength studies of this sort (Martin, 1980; Van Hoven *et al.*, 1980; Webb, Krieger and Rust, 1976; Rust, Nakagawa and Neupert, 1975; Webb, 1983; Kahler and Buratti, 1976) were more limited because of sporadic or slower image cadences, lower sensitivity, poorer resolution, or fewer wavelengths available. In addition to a broader range of data

with better coverage, we also had the advantage of observing the sun at its maximum level of activity, with flares occurring six times more frequently than during the Skylab period.

Our approach was to assemble all available preflare data for a number of well-observed events and the results of several "cross-sectional" studies in specific wavelength ranges. We have selected good simultaneous observations at as many levels of the solar atmosphere as possible, from the photosphere through the chromosphere and transition region to the lower and middle corona. We concentrated on data with time resolution ranging from tens of seconds to minutes, collected over a time interval ranging from about one hour before the flare up to impulsive onset as defined in hard X-rays by HXRBS. In very few cases were observations at all levels of equally high quality, but a sufficiently large set of well-

Table 1.4.1a

Wavelength	Instrument	References Discussed
Microwave (spatially resolved)	Very Large Array: 2 cm, 6 cm, 20 cm Owens Valley Radio Observatory Nobeyama Interferometer (17 GHz)	9, 14, 15, 18 10 16, 17, 45, 44
Microwave patrols	Berne University Sagamore Hill Ottawa/Penticton (2.8/2.7 GHz) Toyakawa (1-9.4 GHz)	67, 35 9, 73 M. Bell, pers. comm. 43, 44
H α	Ottawa River Solar Observatory Solar Optical Observing Network Big Bear Solar Observatory Udaipur Meudon	9, 30 9, 36 10, 38 40, 74 34, 55, 80
White Light Corona	Mauna Loa SMM C/P P78-1 Solwind	41, 57, 86 23, 54, 57, 77 J. Karpen, pers. comm.
Ultraviolet	SMM UVSP	9, 20, 21, 29, 40
X-rays, Soft	SMM XRP/BCS SMM XRP/FCS GOES P78-1 Sollex	28, 40, 50, 83 50 S.G.D. 20
Medium-Hard	HXIS	7, 24, 48, 51, 54, 60, 63, 68, 79
Hard	HXRBS	9, 37, 44, 50, 62, 67 69, 71, 78, 82, 83
Gamma Rays	GRE	73, 78

Table 1.4.1b
References for Tables 1.4.1, 1.4.2

1. Martin 1980
7. Machado *et al.*, 1982
8. Kundu *et al.*, 1982
9. Kundu *et al.*, 1985
10. Hurford and Zirin 1982
13. Lang 1979
14. Kundu 1981
15. Kundu and Shevgaonkar 1985
16. Kai *et al.*, 1983
17. Kosugi *et al.*, 1985
18. Willson 1983
20. Woodgate *et al.*, 1982
21. Woodgate *et al.*, 1981
22. Gary 1982
23. Sime *et al.*, 1980
24. Harrison *et al.*, 1985
27. Moore *et al.*, 1984
28. Wolfson *et al.*, 1983
29. Schmahl 1983
30. Gaizauskas 1984
34. Malherbe *et al.*, 1983
35. Simon *et al.*, 1984
36. Rust *et al.*, 1981
37. Rust *et al.*, 1980
38. Zirin 1983
39. de Jager *et al.*, 1983
40. Machado *et al.*, 1983
41. Rock *et al.*, 1983
42. Woodgate 1983
43. Enome *et al.*, 1981
44. Hoyng *et al.*, 1983
45. Kosugi and Shiomi 1983
46. Solar Geophys. Data 4418 1981
47. Dwivedi *et al.*, 1984
48. Duijveman *et al.*, 1982
50. Strong *et al.*, 1984
51. Oord *et al.*, 1984
54. Simnett and Harrison 1984
55. Gosling *et al.*, 1976
57. Gary *et al.*, 1984
60. Schadee *et al.*, 1983
61. Martin *et al.*, 1983
62. Svestka *et al.*, 1982
63. Gaizauskas and Schadee 1984
67. Wiehl *et al.*, 1983
68. Hoyng *et al.*, 1981
69. Dulk and Dennis 1982
70. Tandberg-Hanssen *et al.*, 1983
71. Woodgate *et al.*, 1983
72. Gabriel *et al.*, 1981
73. Cliver *et al.*, 1984
74. Bhatnager 1981
75. Poland *et al.*, 1982
76. Neidig and Cliver 1983
77. Wagner 1982
78. Marsh *et al.*, 1981
79. Duijveman *et al.*, 1982b
80. Malherbe *et al.*, 1983
81. McKenna-Lawlor and Richter 1982
82. Wu *et al.*, 1983
83. Antonucci *et al.*, 1982a
84. Antonucci *et al.*, 1982b
86. MacQueen and Fisher 1983

covered events was available for comparative and statistical analyses. The study of this large set of data continues in order to test the associations noted here between various preflare signatures.

Among the questions guiding this study were:

- Where is the flare trigger located?
- Is flux emerging at the photospheric level a necessary condition for preflare coronal activity?
- Do flares “try” to start, fail, and “try” again?
- Do flare precursors have both thermal and non-thermal components?
- Are there two distinct classes of precursor, some associated with filament activation and some not?

We have organized material leading up to a discussion of these questions as follows. In the next section we define the onset phase and precursors and explain how we distilled our preflare data set. In Section 1.4.3 are presented several key events which illustrate the connections that we discovered

among their preflare phenomena. In Section 1.4.4 we describe an important comparison of the location of preflare activity in FCS and UVSP images. In Sections 1.4.5 and 1.4.6 are reviewed the observations of certain radio precursors which are taken as evidence favouring preheating and non-thermal particle acceleration. Finally Sections 1.4.7 and 1.4.8 describe HXIS observations of X-ray precursors.

1.4.2 Defining the Preflare Regime

We follow Svestka (1976) and Sturrock 1980, (especially p.413) in defining the “onset” of the flare as the time of the first rise in emission at the site of the flare itself. We adopt a somewhat more general definition of “precursor” than used in the Skylab studies (Sturrock, 1980). We take a “precursor” to be a transient event preceding the impulsive phase, possibly even before the onset and not necessarily at the precise site of the flare itself.

The initial sample of preflare events included 54 flares selected by Woodgate to have sufficient coverage in time by UVSP and BCS before the impulsive hard X-ray burst recorded by HXRBS. When multiple bursts occurred, the largest was taken to be the primary flare. In this respect, the study was similar to that of Webb (1983), in that "minor" flaring was included as "preflare" activity. From a combination of Woodgate's sample with 12 other events which showed interesting preflare activity in microwaves, $H\alpha$, white light and/or in X-rays, we selected 26 events which had the best overall coverage in data for concentrated study. These events along with key precursor observations and references to publications are summarized in Table 1.4.4.

1.4.2.1 The Onset Phase

We defined two onset times for each of the primary flares in Table 1.4.2. One was the impulsive onset observed in hard X-rays (HXRBS). The other was the soft X-ray onset, commonly defined as the start of the rise of the flare flux profile. Webb determined the onset time in this manner, using the full sun 1-8 Å X-ray flux recorded by the NOAA/GOES satellite for the events in this study. On average, the soft X-ray onset occurred ~ 2 minutes before the onset of the hard X-ray burst, in agreement with previous results (Svestka 1976). Schmahl, Strong and Waggett used background-corrected BCS light curves in a similar way to determine the soft X-ray onset times. These onset times and the hard-X-ray minus soft-X-ray time differences are shown in Table 1.4.2.

There was surprising agreement between the GOES and BCS (Ca XIX: ~ 3.2 Å) timings, with onsets rarely differing by 1 minute in the two X-ray regimes. When differences arose the BCS data were used since its $6' \times 6'$ (FWHM) field of view minimized confusion from flares in other regions. Since Ca XIX is formed at $\sim 1.5 \times 10^7$ K, the onset profiles indicate the existence of pre-impulsive plasmas as hot as $\sim 10^7$ K.

Harrison, Schadee and Schrijver plotted onsets for a number of flares using the softest channel (3.5-5.5 keV) of the HXIS instrument. Several onset profiles are shown in Figure 1.4.1a. The profiles of Figure 1.4.1a were integrated over the full coarse field of view ($6'.2 \times 6'.2$), and therefore may represent the sum of more than one onset source. Figure 1.4.1b illustrates the comparison of onsets for the full field of view and for four areas of a few pixels each at and near the flare site, 18:17-19:03, 28 June 1980. We shall return to this flare later, but for now we note that the full field-of-view integration shows an earlier onset than the flare pixels themselves, suggesting preheating away from the flare site. Pre-onset activity has been noted outside of the flare structure before, especially in the Skylab data (e.g., Van Hoven 1980, Webb 1983, Kahler and Buratti 1976) and SMM data (e.g., Machado *et al.*, 1982). However, at this stage it is not clear how to compare the results from Skylab and SMM.

For instance, the X-ray filters on the Skylab AS&E experiment defined plasmas of lower temperature ($\sim 1.5 \times 10^6$ K for the softest filter) than the SMM BCS ($> 8 \times 10^6$ K) and HXIS (greater than or about 10^7 K) experiments. There was no hard X-ray detector aboard Skylab so it was not possible to compare directly the distribution of soft X-ray to impulsive onsets. Since the Solrad or GOES maximum almost always followed the impulsive maximum by a few minutes, the Skylab onset times would have to be modified for comparison with this study.

The fact that a gradual onset in soft X-rays or microwaves is always present suggests a thermal origin for the first phase of flares (e.g., Svestka 1976). Machado *et al.* (1982) have suggested that the preflare gradual phase is a manifestation of the same phenomenon as the post-flare gradual phase. However, while this is conceivably true of the soft X-ray emitting regions, the gradual phase in microwaves shows remarkable differences (in polarization or source-size changes) preflare and post-flare (e.g., Kundu *et al.*, 1985, Hurford and Zirin 1982). More study is required to determine the nature of the gradual onset of flares. We show below, in examples reported by Team members, several physical interpretations in terms of heating, upheavals or reconfigurations of magnetic flux.

1.4.2.2 Flare Precursors

The SMM data base is much more continuous than that of Skylab, and it is therefore possible to make stronger distinctions about flare precursors. In the more sporadic Skylab coverage (Webb, 1983; Kahler and Buratti, 1976; Kahler, 1979), it was more difficult to distinguish precursors from the onset phase. When such a precursor was observed, we defined the onset of the flare "conservatively" by the last pre-impulsive phase minimum of the light curve.

Since it is difficult to distinguish a true precursor signal from the flare onset or rise phase itself, when it occurs within a few minutes of the impulsive phase (Kahler 1979), we emphasized analysis of observations from about 60 to 5 minutes before impulsive onset. SMM images sometimes revealed precursors which were physically distinct from the flare, during what would otherwise be defined as the gradual onset phase.

X-rays. Precursors in the high resolution X-ray photographs from Skylab appeared as loops or kernels close to, but not necessarily, at the flare site. Often these sources were multiple and small (several arc-sec). In many cases, the precursors were closely associated with activated filaments (Van Hoven 1980, Webb *et al.*, 1976, Webb 1983).

Examples of all of these effects are present in our SMM data set. In terms of the SMM X-ray light curves, gradual-rise-and-fall (GRF) precursor signatures were frequently detected in X-rays (Figure 1.4.1) and microwaves. Such a signature is considered indicative of coronal heating and is strongly associated with filament activations (Martin 1980,

Table 1.4.2 Event Summary of SMY Precursors

Date (1980)	Flare ¹ Peak Flux	Implsv. Onset (HXRBS)	SXR ΔT $\Delta T^{(2)}$ $\Delta T^{(3)}$	H α flare ⁴ or burst	Fil. Act. -Onset	Rising Loop or Trans.	Brightenings ⁵	Microwave Patrol Intensity Change	Microwave Pol. Change	Radio Spectral Events	Event References
Mar 23	C7	1658.3	(4)/--	N	Y-1600; 1648		H α	Inc:1648	Inc. + Rev.	NONE	10,47,78.
Mar 29	C31	2041.3	4/--	Y-2016			SXR,UV,H α	?	Inc:2016	III, V	—
Apr 6	C7	0716.5	(7)/?							I, III	—
Apr 10	M4	0917.1	7/22				SXR,UV	Step:0903		NONE	7,27,40,48, 68,74,83,84.
Apr 30	M2	2022.1	4/28			Filling loop	SXR,UV,H α	GRF:2020- 2215		NONE	1,36,37,39,72.
May 15	M2	--		Y-2019				GRF:2030- 2130	Dec. + Rev.	III	10
								Inc:1935			
June 19	M1	1838.2	(8)/(8)	N			UV,H α	GRF:1742- 1810	Dec.	I, III	10
June 22	M1	--	--/(~50)	N	Y-1250	Inferred	H α	GRF:1300- 1830		I, III	34,35,61.
June 25	M1	1551.3	11/31	Y-1522	Y-1530	Inferred	SXR,HXR, UV,H α	Step:1520	Inc. + Rev.	I, III	8,9,14,20, 30,47.
June 26	M4	2339.8	1/8?	Y-2315	Y-2330		SXR,UV,H α	GRF:2310- 2330	NONE	I, II	29
June 28	C5	1845.3	3/--	N	Y?	HXIS trans. C/P chg.	SXR,UV	NONE		I, III	24,29,41.
June 29	C4	0233.0	0/24	N	Y?	HXIS trans. C/P trans.	SXR,UV,H α	NONE		I: <0231	22,24,29,54, 57,70,77,81.
June 29	M4	1040.2	0/11	N	HeI Loop <1040	HXIS trans.	SXR,H α ?	NONE		III	24,29,54,67,77 81.
June 29	M4	1822.0	0/20	Y-1803		HXIS trans. MLO trans.	SXR,UV,H α	GRF:1701- 1741		III	23,24,29,54,75, 81,82,83.
July 1	M5	1626.8	5/8	Y-1626			H α	Fall:1430 1600	Dec.:1619	NONE	10,47,67,72. 76,84.
Oct 11	X2	1304.3	1/--				SXR,UV	NONE		NONE	
Oct 11	C2	1740.2	0/(40)	Y-1700	N			SXR,H α 2045	GRF:1730-	III	10
Nov 2	C7	0207.8	2/--	N			SXR,UV	NONE		III, V	70
Nov 5	C6	2225.9	0/--	Y for 2232 flare	Active Fibrils	SXR,HXR,H α		GRF:2140- 2220		III	28,42,44,45,46, 48,49,51,79,84.
Nov 8	M4	1440.3	1/8	Y-1354 ⁶			SXR,UV,H α	PBI:1350- 1600		III	71
Nov 11	C8	0626.3	1/>21	N			SXR,UV	GRF:0600- 0650		III, V	—
Nov 11	M1	2051.4	10/23	?			SXR,UV,H α	Rise:2030	Dec.	I, III: >2016	10
Nov 12	C5	2231.1	6/43	Y-2155	Y?		SXR,UV,H α	GRF:2020- 2030	Active	I, III	—
Nov 13	M1	--	--/?	?-1712			H α	Rise:1718	Dec.	I	10
Nov 23	M2	1840.2	(7)/(50)	Y-1754, 1815			H α	GRF:1833- 1922	Dec.	NONE	10
May 1, 83								GRF:2051	Inc.		15

NOTES:

1. GOES-2 I-8Å flux: C1 = 10^{-6} w/m², M1 = 10^{-5} w/m², X1 = 10^{-4} w/m².
2. Time difference: HXRBS Impulsive onset minus SXR flare onset from BCS. GOES data used when BCS not available. GOES Data in ().
3. Time difference: HXRBS Impulsive onset minus earliest SXR precursor in BCS.
4. H α subflare or flare, radio burst or X-ray peak in preflare interval. Y=Yes; N=No.
5. Preflare brightenings in active region: SXR = soft X-rays, HXR = hard X-rays (> 15 keV), UV = UVSP, H α = from H α images.
6. No H α flare patrol: 1415-1515 UT.

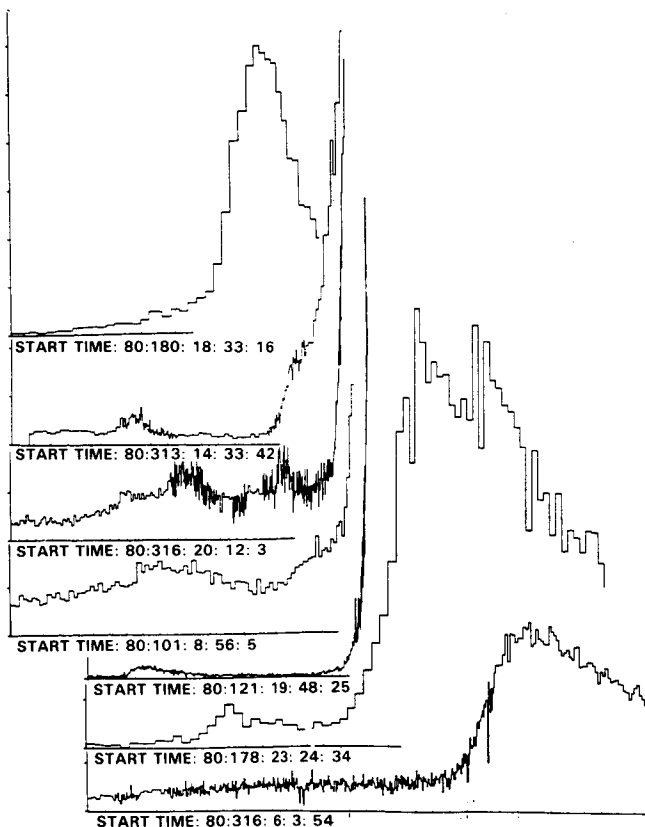


Figure 1.4.1a Onset profiles for a number of flares observed by HXIS in the softest (3.5-5.5 keV) band.

Van Hoven 1980, Webb *et al.*, 1976, Rust *et al.*, 1985, Sheeley *et al.*, 1975, Webb and Kundu 1978) and mass ejections (Harrison *et al.*, 1985, Simnett and Harrison 1984, McKenna-Lawlor and Richter 1982, Kahler 1977).

Microwaves. In the cm- λ regime as observed with interferometers, precursors may appear in the preflare hour as changes in circular polarization (Lang 1974, 1979), enhancements in polarization and intensity (Kundu 1981, Kundu *et al.*, 1982, 1985, Kundu and Shevgaonkar 1985) small impulsive prebursts (Kai *et al.*, 1983, Kosugi *et al.*, 1985), or gradual rises in intensity accompanied by a decrease in fractional polarization (Hurford and Zirin 1982). Simultaneous observations with the VLA and Westerbork Synthesis Radio Telescope (WSRT) (Willson 1983) have shown examples of preburst 6 cm heating near the footpoint of one of the loops which flared. However, other observations have shown that preburst changes are not usually detected, since only 1 out of 8 bursts observed at 2, 6, and 20 cm showed pre-burst activity at the burst site (Willson and Lang 1984), and only 8 of 27 10.6 GHz bursts showed preburst activity (Hurford and Zirin 1982). X-ray precursors were found a majority of the time in the flare active region (Webb 1983), namely, 17 out of 23 cases. So the question arises whether the lower rate of occurrence of microwave precursors is a selection

effect, a threshold effect or a function of the pre-flare energetics or production mechanisms.

Ultraviolet. Some examples of UV precursors include preflare surging motions in C IV (Kundu *et al.*, 1985, Woodgate *et al.*, 1982), and rising loops (Woodgate *et al.*, 1981); these enhancements will be discussed for individual events below. In Section 1.4.4 Waggett and Bentley report on the correspondence of precursors in ultraviolet and X-rays.

Coronal White light. Various observers (Gary 1982, Sime *et al.*, 1980, Harrison *et al.*, 1985, Gary *et al.*, 1984, Wagner 1982) have discussed the early appearance of coronal mass-ejection transients. SMY observations of transients in the low (HXIS) and mid-corona (Mauna Loa) have given a manifestation of pre-onset activity, which is clearer than the Skylab "forerunners" (Jackson and Hildner 1978). The physics of the relation of coronal transients to flares and their respective precursors remains unclear but some preliminary concepts will be presented in Section 1.4.7.

Common Precursor Factors. The variety of precursors seen during the SMM period is surprisingly large but as we shall show, there appear to be common factors that connect them. Emergence of flux at the photospheric level is one such factor, but does not appear to be a necessary condition for the precursor, as shown by the discussion of the 25 June 1980 event in Section 1.4.3.1

A particularly important question for flares in which a filament eruption occurs is whether the uplift of the filament signifies a reconfiguration of the magnetic field that causes the main phase of the flare to begin. There is no question that, typically, a significant amount of energy is released before the impulsive phase begins and before the most violent part of the filament eruption (Webb *et al.*, 1976, Martin and Ramsey 1972, Moore *et al.*, 1984). But precisely where the preflare heating occurs, relative to the observed filament motions and the flare site, is a more central question. Several important flares with well-observed preflare activity are described below in an attempt to access the important parameters and common features of such activity. These features will be summarized in the last section.

1.4.3 Specific Illustrative Events

We have selected 12 well-observed events from our preflare study to illustrate the diverse physical phenomena observed in the corona before flares. These include data with the best imaging and spectral coverage. This selection rules out spurious instrumental effects or unwarranted interpretations that might arise from the data from a single instrument. In a few cases the preflare and flaring periods have been thoroughly analyzed, and the interpretations are not likely to change significantly. But for most of these cases, the analyses are still very preliminary. The reader is cautioned, therefore, that this discussion is only meant to provide some initial

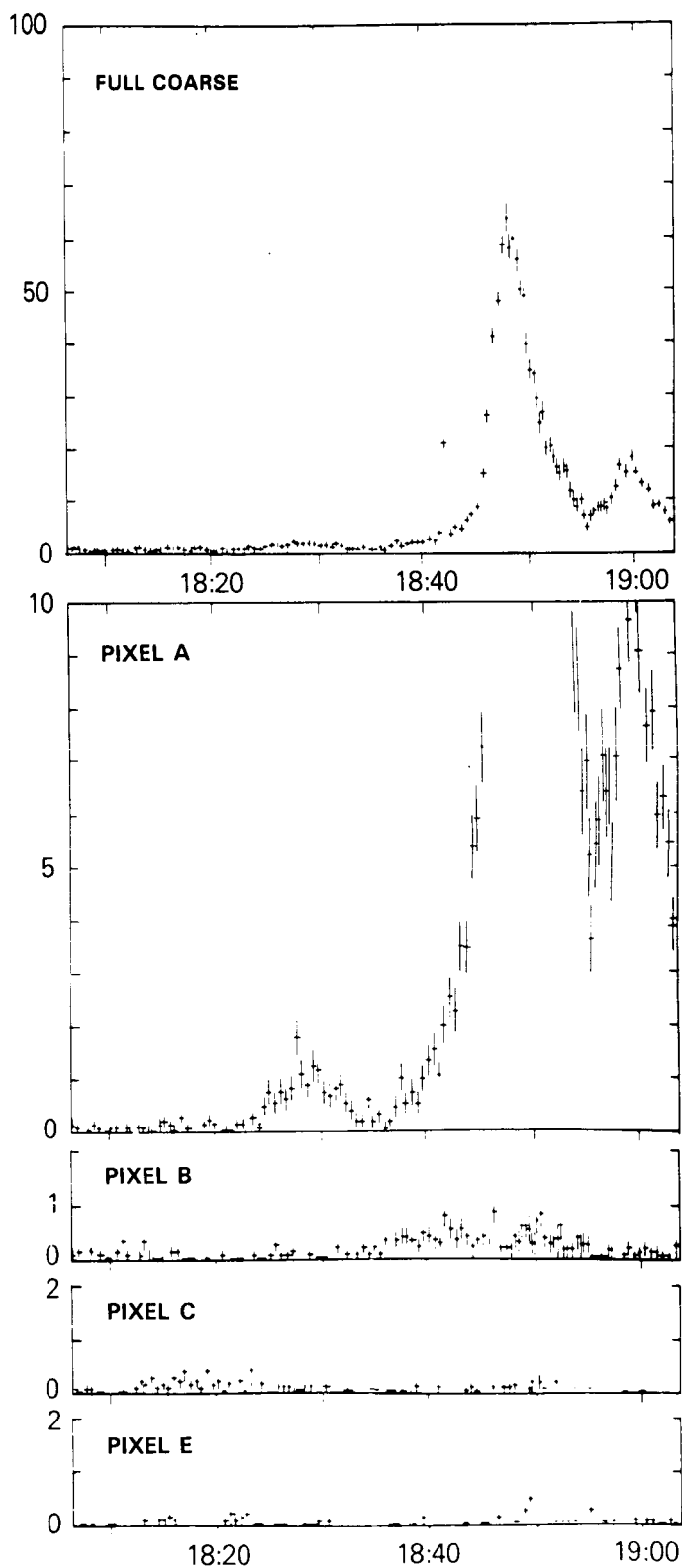
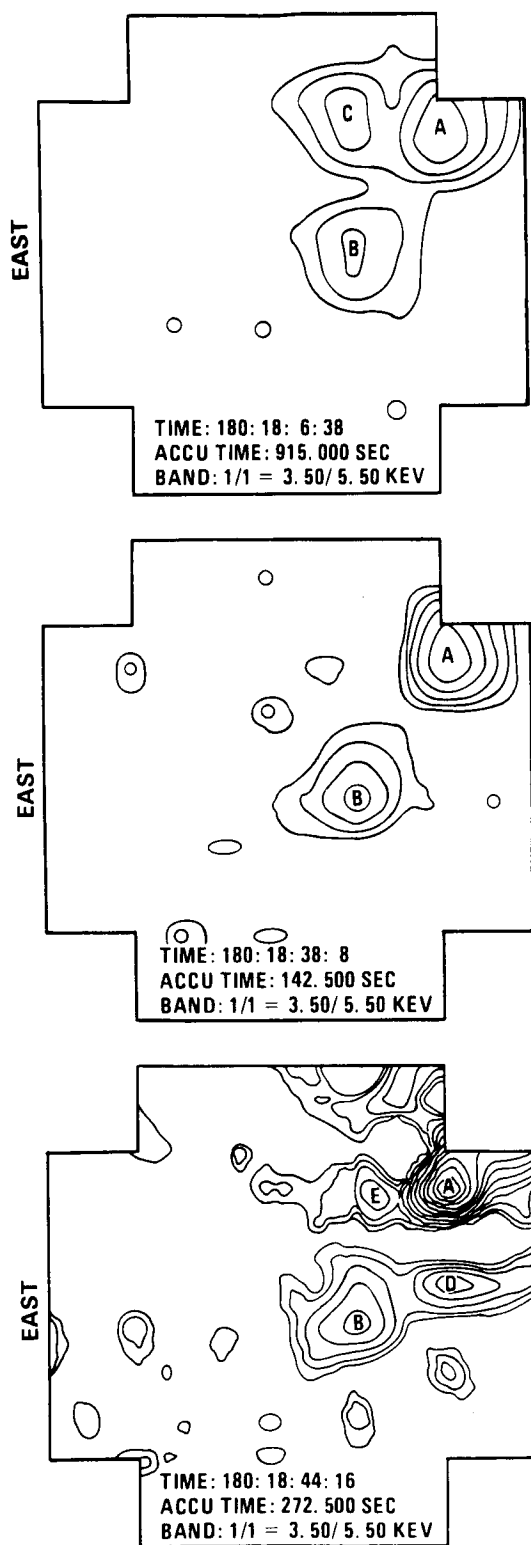


Figure 1.4.1b Comparison of time profiles integrated over the coarse field of view and sets of 1 to 4 individual pixels of the HXIS instrument.

summaries and interpretations of these preflare coronal manifestations.

1.4.3.1 A Filament Eruption Without Emerging Flux (25 June 1980)

The initial source of interest in this event was the set of preflare microwave maps made at 6 cm using the VLA. In the hour before the flare onset (1548 UT), according to Kundu (1981), the region around the flare site showed intensification in several compact (less than or about 20") sources whose polarization increased up until flare onset. In the 15 minutes before onset, the polarization of one bipolar source reversed sign, and the subsequent 6 cm burst occurred at the site of that reversal (Kundu *et al.*, 1982). It was deduced that magnetic changes were taking place during the pre-flare period (Kundu 1981). When he realized that the preflare period contained a well-observed filament activation, and that its subsequent eruption had been well observed in both on- and off-band H α at the Ottawa River Solar Observatory (ORSO), Gaizauskas undertook an exhaustive analysis of the kinematics of the event (Kundu *et al.*, 1985, Gaizauskas 1984). Woodgate (Woodgate *et al.*, 1982), recognizing the significance of simultaneous C IV upflows before the same flare, also undertook a complete analysis of the UVSP dopplergrams. We briefly summarize the details of this event, which have been described at greater length elsewhere (Kundu *et al.*, 1985, Schmahl 1983).

Figure 1.4.2 shows the time line of the preflare period as observed in hard X-rays, soft X-rays, Ultraviolet, H α and microwaves. The main (1B) flare began at 1548 UT (HXRBS), with an earlier minor burst at 1522, which corresponded to an H α subflare seen in the 1' \times 1' UVSP field of view and recorded in the BCS Ca XIX and Fe XXV channels. (There were no imaging X-ray observations of this flare from either SMM or P78-1). Although the subflare had kernels within 20"-30" of the flare-associated filament, the filament motion was not affected. The filament showed steady transverse motion (see Figure 1.4.2) as early as \sim 3 hours before onset, with upward doppler shifts near its midpoint and axial flows and twisting motions along its length. Brightenings at 6 cm were seen in a 5 minute VLA map at the time of the subflare, but the source of emission was \sim 1' from the H α and ultraviolet brightenings. It is likely that this prior radio brightening was related to the magnetic field changes taking place before the onset of the main flare. Just after the subflare, (15:33-15:38), a brightening and upflow occurred in the C IV dopplergram image, coincident with the rising portion of the H α filament which also showed enhanced axial flows. The brightening and upflow reappeared more strongly from 15:42-15:46 in approximately the same location. Finally, a third brightening and upflow reappeared even more strongly at impulsive onset (15:49). By this time the transverse motion of the H α filament had carried it further southward, so that the blue-shifted, impulsive, C IV

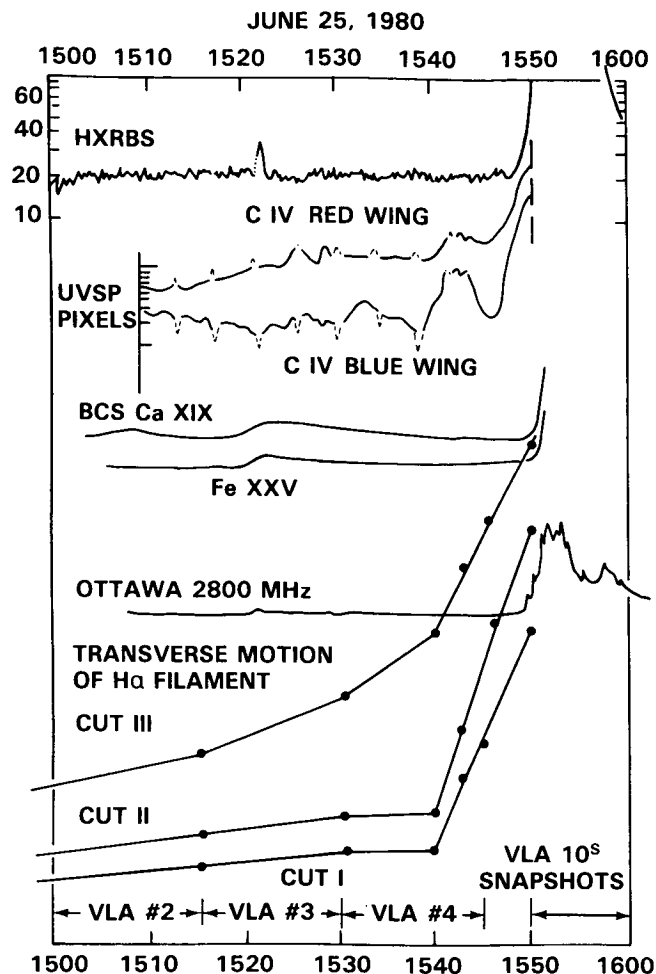


Figure 1.4.2 Time profile of hard, soft X-rays, UV, H α and microwaves for the 25 June 1980 flare. (Courtesy B. Dennis, M. Bell). Note the two BCS maxima at 15:07 and 15:34 UT. Only the 2nd of these was recorded by UVSP.

brightening seen in the last UVSP image at 15:52 UT was clearly north of (and presumably below) the rising filament.

In the last VLA preflare map (15:30-15:40) there was a polarity reversal in one of the bright active region components ("B" in Kundu *et al.*, 1982). The location was cospatial with the subsequent ultraviolet and microwave impulsive onset at \sim 15:50. This was interpreted as possibly due to the interaction of new magnetic flux with pre-existing flux, creating increased 6 cm opacity through the gyroresonance process.

However, careful examination of the ORSO H α films (Gaizauskas 1984, Kundu *et al.*, 1985) and magnetographic data revealed no signature of emerging flux at the chromospheric or photospheric level (Section 1.4.3b). The main conclusion was that changes in magnetic field strength were mainly coronal, with photospheric changes being gradual or evolutionary in this event.

Gaizauskas (1984) has argued that the instability of the filament developed out of a major disturbance in a magnetically connected structure in the same active region. The slow upheaval of the entire structure exhibited enhanced axial flows leading to a rapid twist, consistent with the weak kink instability (Sakurai, 1976; Hood and Priest, 1979; Sung and Cao 1983).

The three preflare rising motions, seen in the ultraviolet, occurred beneath the $H\alpha$ filament (see Figure 1.4.3), which responded with enhancements of axial flows from its midpoint towards the eastern footpoint. The first two episodes of rising motions in C IV were of lower velocity and density than the third. Kundu *et al.* (1985) have suggested that the coronal conditions were such that the first two uplifts were not sufficient to trigger the final disruption of the filament, but that the third one was. The restructuring of magnetic fields before 15:45 UT, suggested by the VLA map must be related to the rising, twisting motions of the filament and its supporting field lines.

1.4.3.2 Filament Eruption with Colliding Poles (22 June 1980)

The preflare activation of a filament on June 22, 1980 serves as an interesting counterpoint to the event of June 25. The region in which the activity occurred, Hale 16918, was studied extensively as part of an SMY FBS interval (Martin *et al.*, 1983), and the filament activity was initially described by Malherbe *et al.* (1983). At the workshop, Simon presented results of a more complete study of the event with an interesting interpretation in terms of current sheets (Simon 1984).

The hard X-ray burst associated with this event was not recorded by SMM because of orbital night. (P78-1 Monex data may exist, but has not been reduced). The microwave impulsive phase of the event occurred between 13:03 and 13:06 UT. At 5.2, 8.4, and 11.8 GHz, an impulsive burst was recorded at Berne from 13:02:40 to 13:03:40. At 3.2 GHz (Berne) and 2.8 GHz (Ottawa) the strongest impulsive burst occurred about two minutes later (13:05:20). Almost simultaneously (± 1 minute) another flare occurred in a neighboring region making the full-disk data difficult to interpret. This second flare occurred along the same neutral line and the two flares may have been related.

The $H\alpha$ flare began in close coincidence with the impulsive bursts, with the central $H\alpha$ intensity in the brightest kernel rising most rapidly from 13:03 to 13:06 UT (Malherbe *et al.*, 1983). The $H\alpha$ intensity and velocity profiles are shown in Figure 1.4.4. The filament associated with this flare showed activity as early as 12:36 UT in the form of red and blue shifts at various locations along its length (Figure 1.4.5). Figure 1.4.5 shows the $H\alpha$ intensity and velocity maps at 13:00 U.T. Systematic blue shifts began at about 12:45 in the filament, where it passed through region designated "O" by Martin (1983). At the western end of the field of view, where the filament was darkest, the velocities were generally small but became redshifted during the main phase of the flare. At the opposite extremity of the filament (C_2) on the other side of "O", blue shifts also changed to red shifts during the main phase. Near the midpoint (C_1) of the filament and "O", the Doppler shifts became large toward the blue side. This behavior is qualitatively similar to that of the June 25 filament. The $H\alpha$ profiles made north of the neutral line showed evidence of absorbing material moving transversely

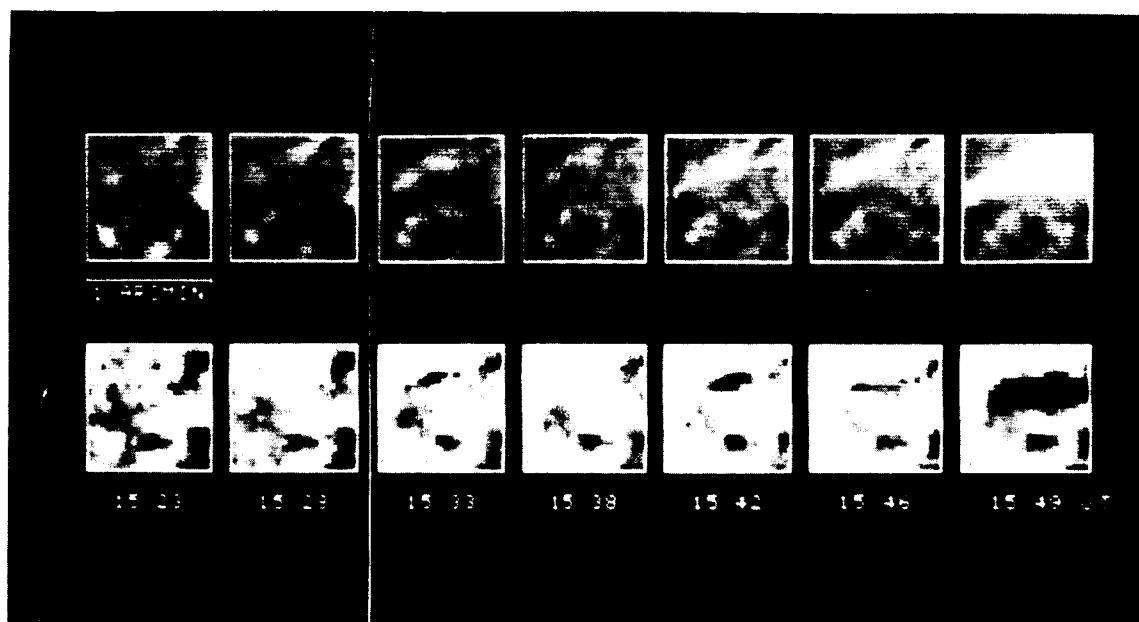


Figure 1.4.3 Rising motions and intensity fluctuations as shown in C IV dopplergrams and spectroheliograms for the preflare period, 25 June 1980. (Kundu *et al.*, 1985).

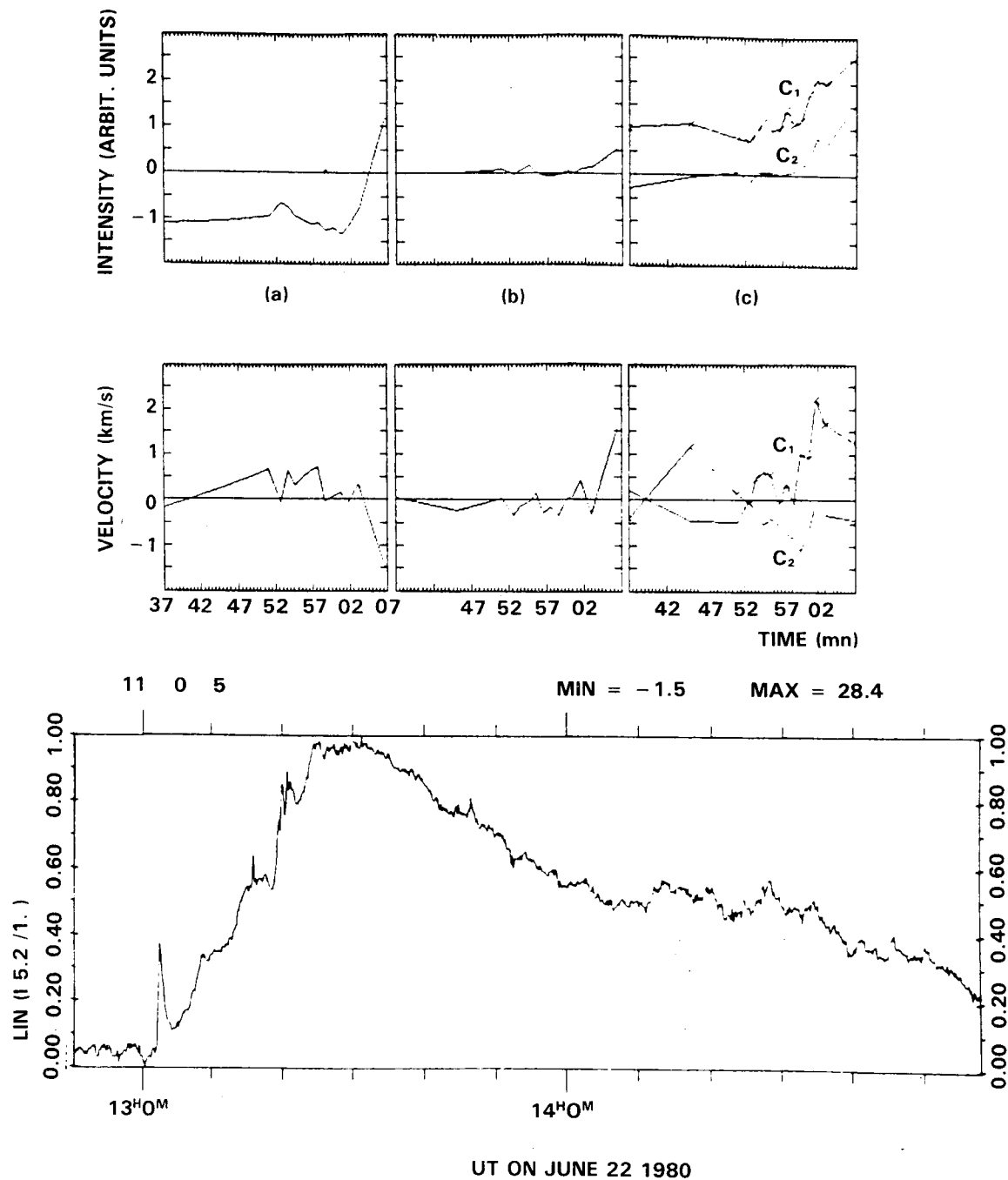


Figure 1.4.4 Time profiles of H α and microwaves for the preflare period, 22 June 1980 (Simon *et al.*, 1984). Upper: H α intensity. Middle: H α velocity. Lower: Microwave flux.

(northward) away from the neutral line between 13:00 and 13:03. The transverse velocity was $\sim 35 \text{ km s}^{-1}$ and the vertical velocity was at least 50 km s^{-1} . The ejected material remained connected to the filament at a point near "O" until 13:05, at the time of the impulsive phase.

During the rise of the filament, 12:59–13:04 UT, the brightest H α knot near "O" moved systematically toward the neutral line with a transverse velocity of 20 km s^{-1} . On

the other side of the neutral line, the knots did not show significant motion. At the time of the H α explosive phase ($\sim 13:06$) the absorbing material north of the neutral line separated. The filament reformed soon after the flare, as it did on June 25. The moving knot was interpreted (Simon *et al.*, 1984) as the foot of a current sheet separating emerging and pre-existing fluxes.

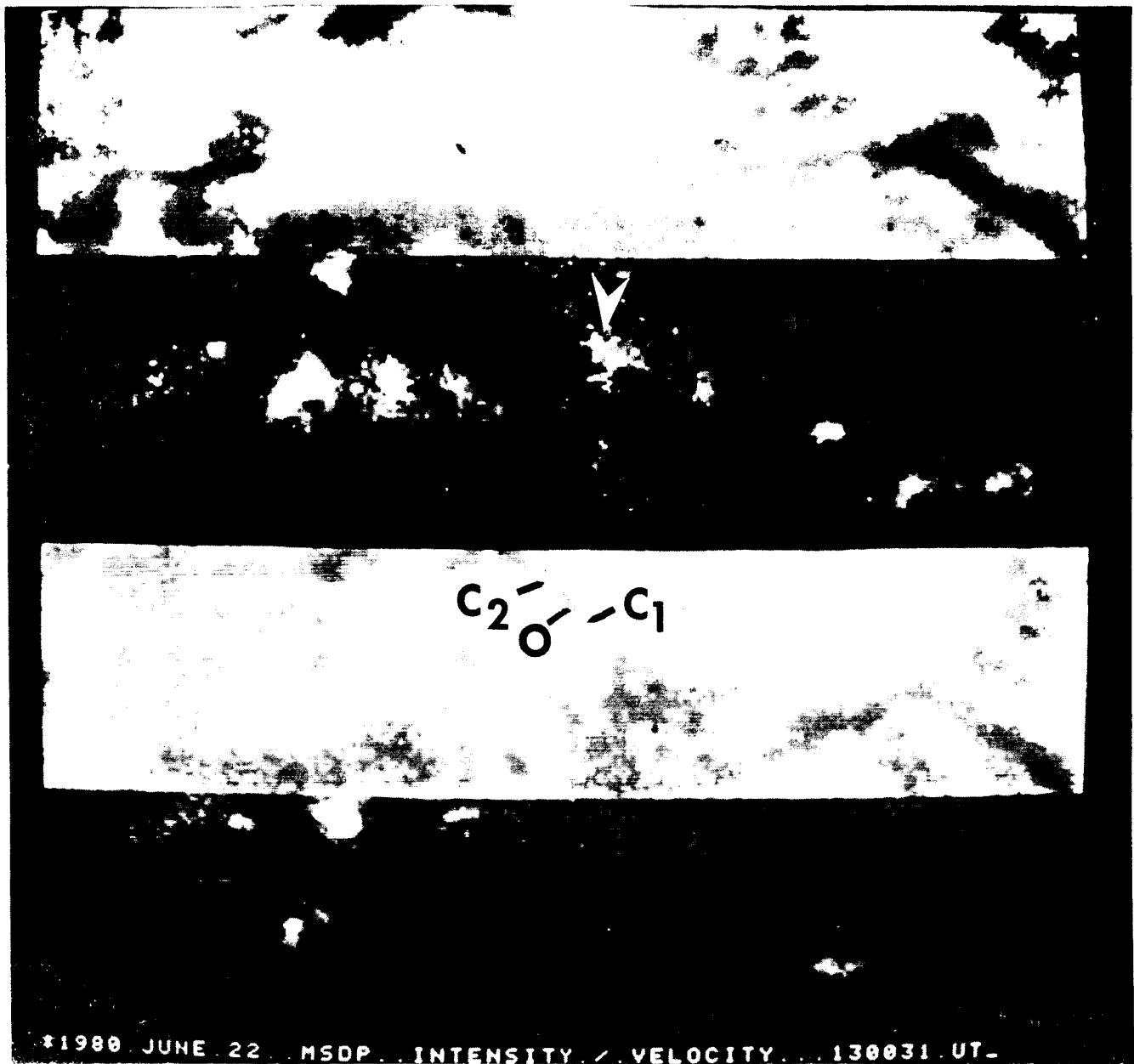


Figure 1.4.5 Intensity and Velocity in H α at 13:00 UT, 22 June 1980. The arrow in the second panel shows the blue-shifted material at "O". C₁ and C₂ in the third panel show the locations of the features of Figure 1.4.4.

Common Features of the June 22 and 25 Preflare Activity

Although the instrumentation observing the events of June 22 and 25 was different and the published descriptions emphasize different physical phenomena, it is clear that there were several common features in these events.

- *Filament Kinematics* – The upward motions of the filaments occurred near their midpoints, with downward motions near the ends. The driving force which lifted the magnetic arch apparently did not constrain the material from falling down the ends of the structures. In the analysis of

both events it was concluded that not all of the filamentary material was ejected.

- *Multiple Motions* – Several kinds of motions were observed. In the June 25 case, there were axial and twisting motions as well as upflows and downflows. The upflows occurred as three successive events in the 20 minutes before onset. On June 22, upflows occurred during the preflare 25 minutes as three or four upheavals at the brightest point of the filament, but axial and twisting motions were not reported.

- *Exciting Agent* – The trajectory of the ejected material appeared to be directed away from a bright “exciting agent” at lower levels. On June 25, a bright surging feature was observed in the C IV line which could be inferred as triggering the eruption (Kundu *et al.*, 1985, Woodgate *et al.*, 1982). On June 22, the bright feature was an H α knot which moved toward the neutral line as the dark absorbing structure on the other side moved away from it. The bright moving knot was interpreted as the footpoint of the current sheet between colliding lines of force (Simon *et al.*, 1984). Although the two “exciting agents”, seen at lower levels, were morphologically different, a common interpretation in terms of moving magnetic fields is possible for both.

- *Filament Reformation* – In both events, the filament reformed within a few minutes of the impulsive phase. This implies that the boundary conditions of the configuration, especially in the photosphere, remained sufficiently similar that the preflare magnetic field structure was restored post-flare (Kundu *et al.*, 1985).

- *Dissimilarities: Is Emerging Flux Necessary?* For the June 25 flare, a clear case has been made that no emerging flux existed below the filament. For the June 22 flare, the evidence is not so clear, but the colliding poles seen below the filament certainly are not characteristic of the classic emerging regions, which overlie diverging bipoles. However, such cancelling Magnetic Features (Martin, 1984) may have a similar effect to emerging flux in triggering flares (Priest, 1985). In both flares, the triggers for the eruptions may have been slow changes of magnetic field in the neighborhood of the filament. Similarly, one can ask whether the apparently different ‘exciting agents’ (the surging C IV emission and the moving H α knot) be interpreted by similar mechanisms. We return to this question after summarizing another event which shows both common and different features of preflare activity.

1.4.3.3 Rising Loop at the Limb (April 30, 1980)

H α observers (e.g., Martin 1980, Rust *et al.*, 1981, Rust *et al.*, 1980, Webb 1983) have shown that H α emission can precede the impulsive phase by a few to tens of minutes. The April 30, 1980 flare illustrates the case where the initial burst is preceded by a bright H α mound at the site of developing new magnetic fields. (The flare occurred close to the limb where chromospheric footpoints typically are hard to detect.) The above-the-limb H α emission was cospatial with a C IV loop (Woodgate *et al.*, 1981) and was interpreted as an arch-filament system (Rust *et al.*, 1981). Foreshortening at the limb, however, makes it impossible to determine the extent of the loop along the line of sight. For example, the loop might have been an elongated helical structure like a filament seen end-on, as suggested by line-of-sight flows seen in the UV, and by the fact that its southern footpoint was further onto the disk than the northern footpoint (Woodgate *et al.*, 1981).

The preflare period for this event was well observed by all the SMM instruments and the details of the preflare activity were summarized by de Jager *et al.* (1983). Figure 1.4.6 shows the schematic UVSP loops (Woodgate *et al.*, 1981) along with the HXIS light curves (de Jager *et al.*, 1983). The two major HXIS structures in the flare, the “kernel” and the “tongue”, both appeared spatially coincident ($\pm 8''$) with the UVSP structures AB and DE (respectively). The brightenings in HXIS X-rays and in UVSP C IV were also in temporal coincidence as were the softer X-rays seen in the BCS Ca XIX and GOES 0.5–4 Å channels.

According to the HXIS observers (de Jager *et al.*, 1983), after the maximum of the “kernel” precursor at 19:55 until

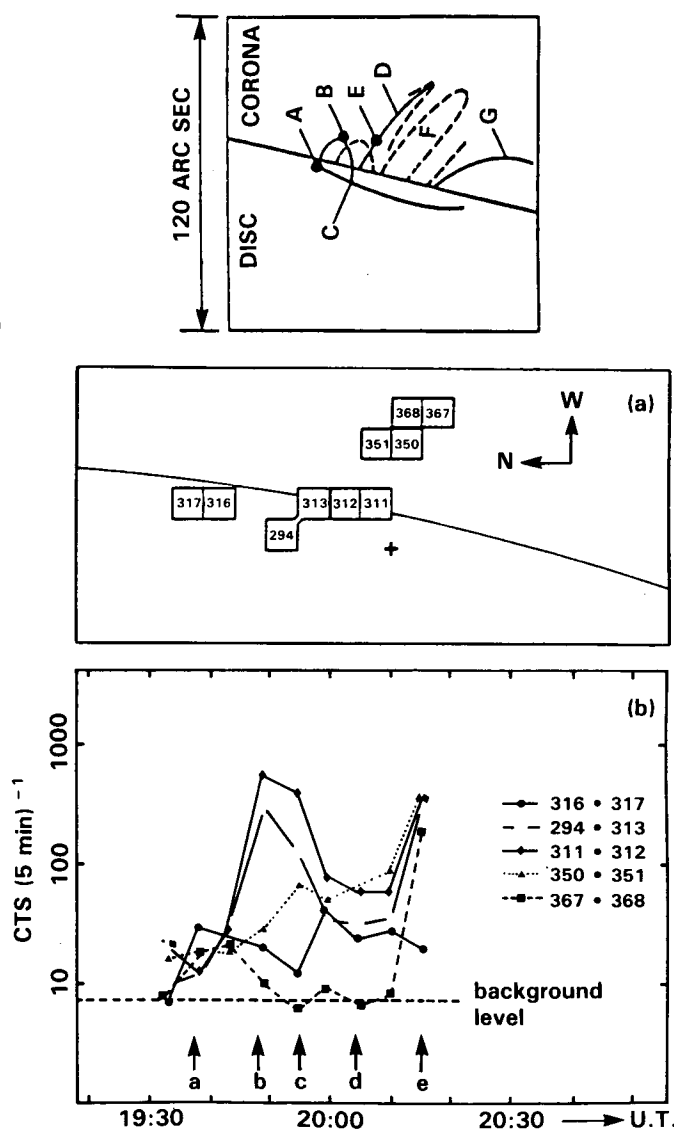


Figure 1.4.6 HXIS light curves (adapted from de Jager *et al.*, 1983) for the April 30, 1980 flare. Schematic loops (Woodgate *et al.*, 1981) are shown above.

the onset of the flare at 20:22, the intensity decline was consistent with conductive losses (no radiative losses) of a gas at $T_e \approx 1.5-2 \times 10^7$ K and $n_e \approx 3.2 \times 10^9$ cm⁻³. In the "tongue", particle energization occurred continuously from the onset of the precursor to the impulsive rise.

During the rise phase (20:17-20:22) of the burst, the H α and soft X-ray emission increased, and material rose in the C IV loop leg, with Doppler shifts (≈ 20 km/s) toward the observer. At the time of the main burst, "breakout" occurred at the top of the loop where a new feature appeared in H α .

Two explanations have been suggested (Woodgate *et al.*, 1981) for the observed developments, the first being that a smaller loop filled with heated gas, pushing it upward into the larger loop and creating the flare at the junction. The second explanation was that the small loop became unstable at the top after the injection of gas and released the gas into the surrounding medium.

The first of these explanations is similar to the scenario developed for the June 25 flare (Kundu *et al.*, 1985), where in the destabilized H α filament was accompanied by rising (C IV) loops. The question of the existence of emerging flux in these events may not be as significant as the similarities in the triggering of the impulsive phase by a rising loop. Whether there was continuous high-energy preflare energization in the June events (as there appeared to be in the April 30 flare) is not known because HXIS did not observe the later pair.

The time profile of soft X-rays [BCS, GOES, HXIS] for April 30, the time profile of C IV intensity and H α velocity for June 25, and the H α velocity profile on June 22 all suggest that the flare "tries to start" and fails until the final agent (rising loop?) triggers the explosive phase.

1.4.3.4 X-ray Precursor Not at Flare Site (April 10, 1980)

The BCS Ca XIX and GOES flux started to rise at $\sim 09:00$, or about 20 minutes before the onset of the HXRBS burst (09:16). During this rise there was a Ca XIX burst ($\sim 09:05$) which is considered a flare precursor. This peak was also recorded by HXIS (Machado *et al.*, 1983) in the two softest channels. Preflare emission in N V was observed in three regions which were postulated (Machado *et al.*, 1983) to be the footpoints of the subsequent flare loops. The 09:05 HXIS precursor appeared mainly at the southeastern and northern footpoints. The UVSP time profile in a $21'' \times 21''$ raster centered on the western footpoint showed impulsive brightening at that footpoint. Woodgate, Waggett and Bentley found that the small UVSP raster precluded an analysis of correlations between preflare ultraviolet bright points and FCS activity.

The combined HXIS and UVSP data imply that the precursor activity occurred in loops displaced $\sim 8''-16''$ away from the main hard X-ray brightening. Machado *et al.* (1983) estimated the emission measure ($\sim 5 \times 10^{47}$ cm⁻³)

and temperature ($\sim 1.3 \times 10^7$ K) for the precursor. The data permitted a multithermal interpretation, but counting statistics did not warrant the computation of differential emission measures.

The authors conjecture that the preflare gradual phase was a part of the overall gradual phase upon which the impulsive phase was superposed.

1.4.3.5 X-ray Preflare Emission From Filament Disruptions

On June 26 1980, Boulder Region 2522/30 produced what Martin classified as a "predictive filament" activation starting at approximately 23:30 UT. The BCS Ca XIX intensity showed a small precursor superposed on the rise at $\sim 23:33$. According to Harrison there were two precursors seen by HXIS at 23:35 (Figure 1.4.7), one located west (limbward) of the subsequent flare site and the other to the east. The BBSO H α film showed that the precursor appeared as a subflare/surge in the penumbra of the leader spots to the west.

During liftoff (23:30-23:40) the activated H α filament went from absorption into emission at 23:39:29 UT, close to the 23:39:35 impulsive onset. For the approximately two minutes of the H α explosive phase, the filament rose rapidly, much like one leg of an expanding loop, after which ribbons formed on either side of the neutral line. Immediately following the flare, the filament reformed.

Preliminary coalignment suggests that the western HXIS precursor at $\sim 23:32$ coincided with the subflare/surge event. The eastern precursor was not obviously associated with any H α activity. Several similarities in the preflare activity of the June 22nd, 25th and 26th events are discussed below.

On June 28, 1980 the leading portion of region 2522/30 was near the west limb and produced prominence and flare activity that was well observed at Mauna Loa Solar Observatory (MLSO) and by SMM. The first sign of activity in the hour before the flare was an eruptive prominence observed by MLSO from 17:12 - 18:44 UT (Rock *et al.*, 1983). Subflares in the region occurred from 18:19 - 18:24. Associated activity was observed by UVSP in the Si IV line from 18:23 - 18:27. The flare itself appeared as two bright knots on the limb, seen in both H α and Si IV. The preflare brightening occurred between the knots, then at the main flare site (18:23 - 18:27). Waggett and Bentley reported what may be an X-ray precursor in Mg XI inside the limb at $\sim 18:18$ - 18:26 (Figure 1.4.8b-d) and then subsequently at the flare site at 18:27 (Figure 1.4.8). The same precursor at the flare site was observed by HXIS in maps prepared by Schadee and Schrijver.

H α flare onset was at $\sim 18:24$ before the onset of hard X-rays and continued as an upflow until at least 18:34 UT. The onset of the flare in X-rays appeared to start at 18:37 in the soft HXIS channel. The Mg XI images (Figure 1.4.8)

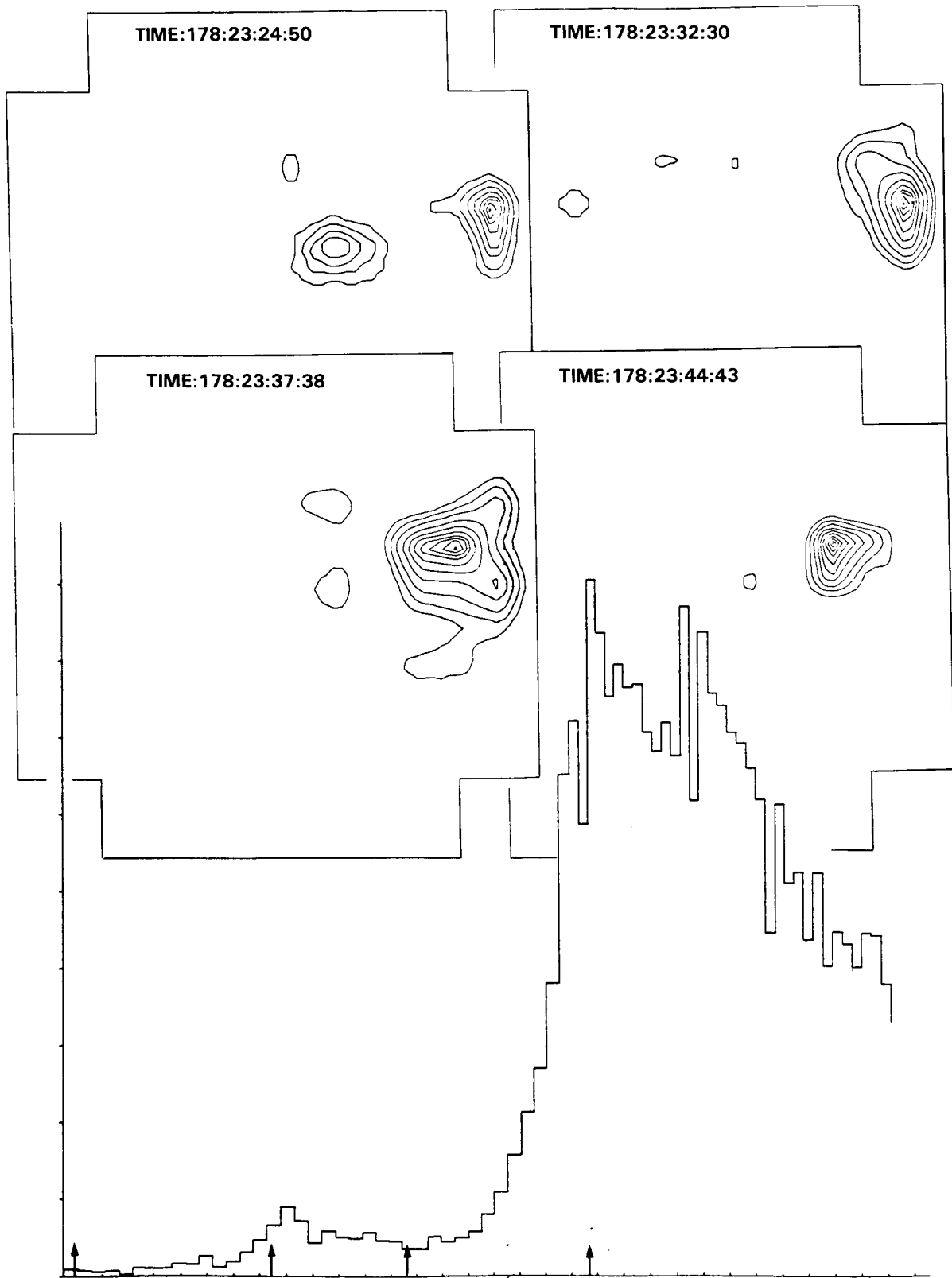


Figure 1.4.7 HXIS images showing the 23:32 precursor before the 23:40 flare on 26 June, 1980. The arrows on the time axis of the burst profile show the times of the individual maps.



Figure 1.4.8 Ne IX and Mg XI (XRP) images showing a precursor, onset and the main phase of the 28 June, 1980 flare. The last Ne IX image is replaced by a white light image. The main flare can be seen in the north-west quadrant of the Mg XI image at 18:44 UT (h). The onset can be seen at the same position at 18:40 UT (g).

showed onset at later than or about 18:42 and a double flare. In Si IV a brightening occurred near the northern flare knot at $\sim 18:41$, maximizing at $\sim 18:45$, the time of the hard X-ray burst. The $H\alpha$ upflows apparently continued through 18:54, with motion paralleling the previous prominence eruption. The outflowing prominence material moved above the

MLSO occulting disk at $\sim 18:59$ at the same position angle as the previous eruption.

Common Activity in the June Events

In the June 26-28 events, preheating of the filament was inferred from X-ray brightening during its liftoff. Both events had $H\alpha$ "double-ribbons"; the June 28th flare was also

double in ultraviolet and X-rays. Preflare brightenings were observed displaced from the flare site. On the 26th, two HXIS preflare brightenings occurred west and east of the flare site. On the 28th, the early Mg XI brightenings were displaced laterally and possibly above the limb flare. Both of these flares require considerably more analysis before firm conclusions can be drawn. Nevertheless, one striking similarity to the June 22 and 25 events stands out. In all four events preflare brightenings (in H α on the 26th and in ultraviolet on the 28th) occurred beneath the filament or between the flare knots, suggesting that the flare was triggered from below. But the subflares preceding the June 25 and 26 flare, and the June 26th and 28th X-ray precursors were all displaced from the flare site and had no obvious relationship to the subsequent flare.

1.4.3.6 Homologous Flaring – November 5, 1980, 22:26 and 22:32 UT

Woodgate (1983) suggested that a majority of flares might be homologous in the sense of having footpoints reappearing very near the same places. The importance of homologous flares is that differences in initial conditions between flares can be minimized in order to isolate which factors are significant in terms of the site of flaring, timing, field strengths and energy release.

The November 5, 1980 flares were a good example of well-observed, homologous events. The hard X-ray profiles were similar (see Figure 1.4.9), although the second burst

was an order of magnitude stronger. The microwave burst profiles were also similar, but the second burst at 17 GHz (Enome *et al.*, 1981) was ~ 40 times larger than the first. The first burst was observed by the VLA at 15 GHz (Hoyng *et al.*, 1983) and by various patrols from 1-17 GHz. The microwave spectrum went as $\nu^{2.9 \pm 0.1}$ up to 17 GHz, and the maximum of the spectrum was therefore above 17 GHz. The patrol data (Nobeyama, Nagoya, and Toyakawa: (Enome *et al.*, 1981, Kosugi and Shiomi 1983, S.G.D. 1981) show that the second burst had a very similar spectrum, also with a maximum ≥ 17 GHz (but less than 35 GHz). The amplitudes of the two events were in rough proportions of $\sim 40:1$ at all frequencies from 1-17 GHz. Helium D3 film from BBSO showed that the two bursts were optically similar (see Chapter 5, §5A.5, Figure 5A.13). The bright D3 kernels of the impulsive phase appeared and disappeared with close simultaneity to the hard X-ray bursts, and the two “kernels” of the second event were cospatial with those of the first. One important difference between the two events was a weak “outlier” seen in D3 far from the main kernels.

According to Martin (see Chapter 5) the outlier appeared to correspond to the weak impulsive source reported by HXIS (Duijveman 1982). Both flares showed strong Ca XIX blue shifts (~ 300 km/s) during the impulsive phase (Antonucci *et al.*, 1984). This bears on the question: did the first flare trigger the second? X-ray observations have shown (Strong *et al.*, 1984) that a flare closely following a previous one can be affected by the presence of thermal electrons exceeding a certain critical density which are “quenched” in the flux tube where the impulsive acceleration of the second flare takes place. If the critical density ($\sim 3 \times 10^{12}$ cm $^{-3}$) is exceeded, the beam electrons will lose their energy at high altitudes, and no chromospheric evaporation will occur (as was the case in the double flare of August 31, 1980). The measurements of strong Ca XIX blue shifts in both flares on November 5 indicate that “quenching” of the second flare did not occur. Since the observations all suggest that the main components of the two flares were co-spatial (not including the outlier), it is likely that both flares occurred in one flux tube and that the critical density was not reached.

Longevity of the X-ray Loops

Martens *et al.* (1985) conjectured that two fairly stable loops in region 2776 dominated the HXIS emission from November 5, 12:30 to November 6, 03:50. These loops were labelled AB and BC (Figure 1.4.10). During this time loop AB flared twice at 22:26 and 22:34 UT with several other flare-like brightenings at 15:04, 17:20, 20:47 and 23:50 on November 5. In the second flare the footpoint C of the impulsive phase was connected to the common footpoint B of the two loops. Apparently, loop BC was quite long-lived (Martens *et al.*, 1985) with small variations correlated with the brightenings in loop AB.

Because loop BC was stable in emission we can assume that it was in static thermal equilibrium. We can therefore use scaling laws (Rosner *et al.*, 1978) to derive the electron

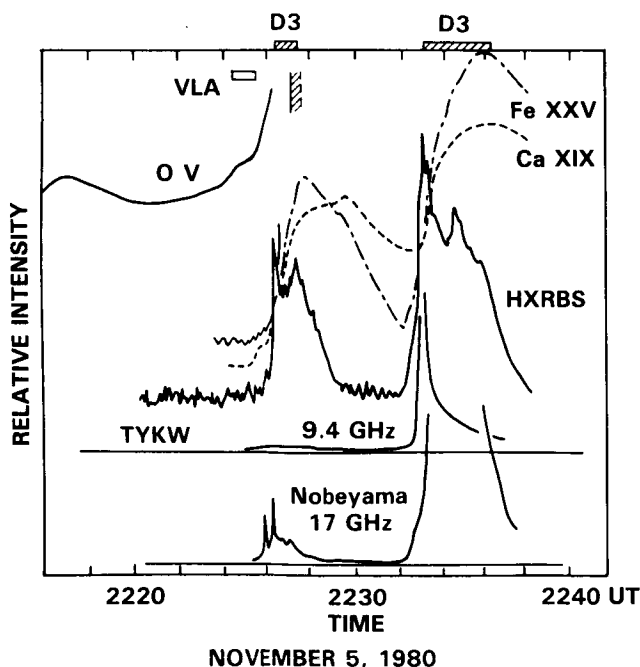


Figure 1.4.9 HXRBS, microwave, and BCS time profiles of the homologous pair, 22:36 and 22:32, 5 November 1980.

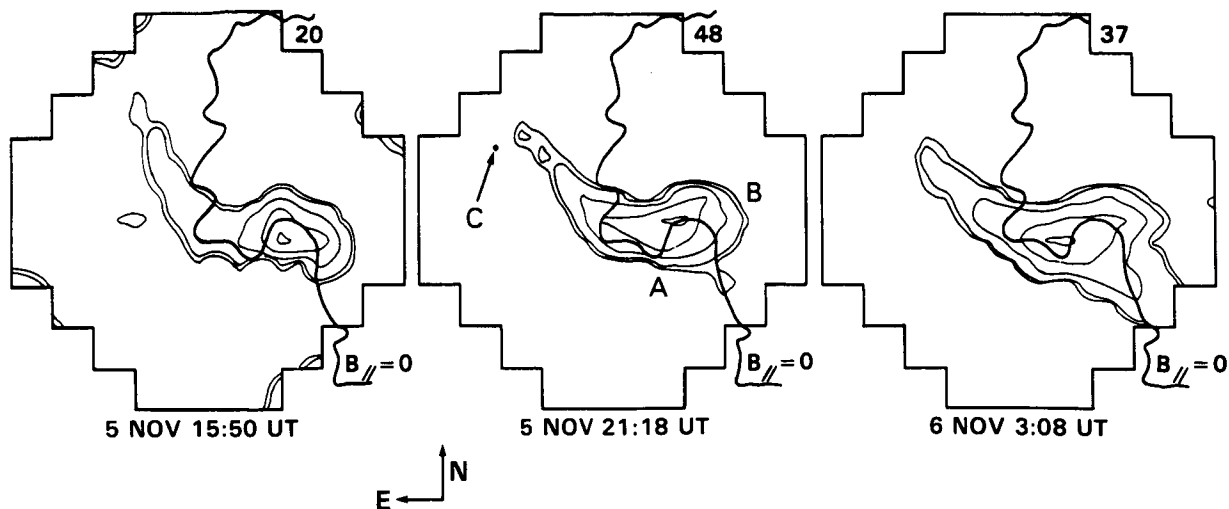


Figure 1.4.10 HXIS images of loops BC and AB preflare and postflare (Martens *et al.*, 1985).

density (n_e) and the heating rate in the loop (E_h) from the observed loop length (L) and temperature (T_{obs}) from HXIS. (We note, however, that the usefulness of the static loop scaling law has been questioned by Roberts and Frankenthal (1980)). From the observed emission measure (Y) and the derived density an estimate of the emitting volume $V_{\text{em}} = Y/n_e^2$ of the loop could be made. This emitting volume was, surprisingly, much smaller than the observed volume $V_{\text{obs}} = L\pi r^2$ of the loop. The loop filling factor: $\phi = V_{\text{em}}/V_{\text{obs}}$ had an almost constant value of 10^{-3} . These results are summarized in Table 1.4.3.

Table 1.4.3
General Data on Loop BC, November 5/6, 1980

Mean Length	$(93.4 \pm 1.5) \times 10^8$ cm
Mean Diameter	$(11.4 \pm 0.3) \times 10^8$ cm
Mean Temperature	$(10.4 \pm 0.2) \times 10^6$ K
Mean Electron Density	$(9.8 \pm 0.4) \times 10^{10}$ cm $^{-3}$
Mean Filling Factor	$(1.4 \pm 0.3) \times 10^{-3}$
Mean Heating Rate	(0.64 ± 0.04) erg cm $^{-3}$ sec $^{-1}$

Similar data on loop AB could not be derived, since it was unresolved by HXIS and its emission was highly variable. During quiescent periods loop AB had a temperature of 10^7 K and an emission measure per ($8'' \times 8''$) pixel of about 1.5×10^{46} cm $^{-3}$. Duijveman *et al.* (1982) derived an electron density of 2.4×10^{10} cm $^{-3}$ from the observed temperature and an emission measure of loop AB by assuming a filling factor of unity, while FCS observations of Ne IX were used to derive $n_e = 1.5 \times 10^{12}$ cm $^{-3}$ (Wolfson 1983). Agreement between these observations is obtained by using

a filling factor of 2.6×10^{-4} , which is of the same order of magnitude as that of loop BC.

Together these observations suggest the continuous dissipation of a current which is present in loops AB and BC, with the actual loss taking place in a very thin region. Clearly during flares the dissipation mechanism changes *qualitatively* in character.

It is still an open question whether the first and smaller burst late on November 5 triggered the second burst, or whether both were triggered by earlier events. The preflare manifestations of these flares have not yet been reported in sufficient detail to assess their significance. It appears, from the BBSO H α film, that the first flare started in a fibril crossing the neutral line. This fibril went into emission at 22:23:29, approximately simultaneously with a rise in OV seen by UVSP, a small rise at 15 GHz (Hoyng *et al.*, 1983) and a rise at 9400 MHz (Enome *et al.*, 1981). Earlier subflares occurred on the same neutral line.

This double flare is important not only for the questions associated with homology, but as a possible test case for double flares in general. It has been estimated (Strong *et al.*, 1984) that $\sim 43\%$ of the ~ 200 largest flares seen by the XRP in 1980 were "multiple" (on the basis that the Ca XIX flux did not fall to background between maxima). The importance of such "multiple" flaring for preflare studies lies in their possible relation to precursors, triggering and the repeated "attempts" of a flare to start.

1.4.4 Comparison of Preflare X-rays and Ultraviolet

Waggett, Bentley and Woodgate compared BCS and UVSP images for those of the 26 events in the Table 1.4.2 that showed pre-impulsive activity in the UVSP images. As both the FCS and UVSP are capable of performing a vari-

ety of different size rasters within large fields of view it is possible for them to be looking at different areas within the same active region. Coalignment of the instruments' fields of view left 10 events with good overlapping spatial and temporal coverage in both UVSP and FCS images.

Two time intervals were considered: the preflare period prior to the HXRBS onset and the impulsive phase prior to the HXRBS peak. The spatial separation of the UVSP preflare bright points and the FCS flare site were divided into three distance categories: less than 20" (adjacent to or at the flare site), between 20" and 40" (close to the flare site), and greater than 40" (far from the flare site). The results are given in Table 1.4.4 where the separation of the nearest preflare pixel is indicated by a 'Y' in the appropriate distance column. The BCS column indicates whether there was significant activity in the BCS Channel 1 light curve during the preflare period and the BDIP column indicates whether

the preflare pixel brightened during the impulsive phase in the FCS data.

With only 10 events it is difficult to form meaningful conclusions. It is hoped that coordinated observations with special observing sequences during the SMM 2 mission will expand the sample. The inclusion of XRP data has improved the results of the UVSP analysis by confirming the position of the flare site and by removing events that were initially confusing. It is clear that the correlation of preflare UV bright point position and the flare site is good since 6 (possibly 7) of the nearest 10 preflare events are coincident with the subsequent flare site.

1.4.5 Preflare Microwave Intensity and Polarization Changes

We discussed in Section 1.4.3 some interferometer observations which showed preflare polarization changes.

Table 1.4.4 Details of the Nearest UVSP Preflare Brightening Pixels for the Ten Events Used in the XRP Comparison

Date	Distance of Pixel			BCS	BDIP	UVSP Line	Pixel Size (arc sec)	Preflare Intensity (UVSP C/S)	Impulsive Phase Intensity (UVSP C/S)
	< 20"	20-40"	> 40"						
29/3/80 (2014 UT)		Y		N	N	CIV	3	1.42×10^4	3.42×10^4
27/4/80 (0106 UT)		Y(*)		N	?	CIV	3	3.42×10^4	NOT SEEN
30/4/80 (2023 UT)	Y			N	N	CIV	3	6.13×10^3	2.76×10^4
20/6/80 (0488 UT)		Y		N	N	CIV	3	2.92×10^3	2.34×10^4
29/6/80 (2022 UT)	Y			Y	N	CIV	3	1.08×10^4	1.66×10^4
10/7/80 (2126 UT)	Y			N	Y	SiIV	3	4.07×10^2	7.00×10^4
11/10/80 (1741 UT)		Y		N	N	OV	10	3.80×10^2	4.28×10^3
2/11/80 (0211 UT)	Y			N	?	OV	10	2.99×10^2	NOT SEEN
11/11/80 (2054 UT)	Y			Y	Y	OV	10	9.06×10^2	1.63×10^3
12/11/80 (2231 UT)	Y			Y	N	OV	10	1.46×10^2	2.59×10^2

Although it may be true (Hurford and Zirin 1982, Willson and Lang 1984) that preflare polarization changes at centimeter wavelengths are not generally detected, there is evidence (Hurford and Zirin 1982) that certain microwave signatures are relatively reliable predictors of flares.

In a study of a sample of 81 major flares observed at 10.6 GHz with the Owens Valley Radio Observatory (OVRO) interferometer, Hurford and Zirin (1982) found a variety of preflare behavior. The most common preflare signature was a step-like increase in signal amplitude I, accompanied by a decrease or reversal in the polarization signal V during the last 10 to 60 minutes before the flare. This signature was found in the first half of the data base (Feb. 19 – Sept. 1, 1980), and when applied by a computer program to the second half (Sept. 1, 1980 – March 31 1981) succeeded in “predicting” five out of 54 flares. This low success rate limits its practical value as a flare predictor but the microwave signatures do illustrate the coronal manifestation of some kind of magnetic activity. Figures 1.4.11a,b show two examples of flares observed at 10.6 GHz by OVRO on July 1 and October 11, 1980. The first shows a signature of increasing I and decreasing V, while the second shows only increasing V. Kundu (1981) suggested that the cause of microwave enhancements and polarization changes may be increasing magnetic field strength at the coronal level. The increasing magnetic field causes new loops to become optically thick at low harmonics (2nd, 3rd, and 4th) of the gyro-frequency. Depending on the relative orientation of the pre-existing and new loops, the polarization can increase (Lang 1974, 1979), flip (Kundu 1981, Kundu *et al.*, 1982) or decrease (Hurford and Zirin 1982). Only two-dimensional interferometry (VLA) can resolve the loop geometry, and there are still too few examples from OVRO to infer the loop geometry statistically. Hurford and Zirin (1982) showed in 3 cases that microwave changes were associated with subflares or filament changes. The July 1 event illustrates an example of a preflare brightening in H α (at \sim 16:18), near the start of the increase in one of the polarization channels. The June 25 flare reported above in Section 1.4.3.1 illustrated another association between microwave and H α changes.

The gradual rise in preflare microwave intensity can be observed with patrol instruments, and is presumably associated with “preheating” and gradual rises in soft X-rays (see Section 1.4.2). These gradual increases in microwaves are frequently associated with filament activations (Webb *et al.*, 1976, Sheeley *et al.*, 1975, Webb and Kundu 1978) and were observed by patrol instruments for the June 22, 25 and 26 flares discussed above. The OVRO amplitude for the July 1 X-ray flare (Figure 1.4.11a) showed a preflare increase that was not observed by patrol instruments or in the Ca XIX time profile. Thus the heating effects may have been too small to be observed in X-rays, but a microwave increase was observed possibly because of the extreme sensitivity to the mag-

netic field in the cyclotron emission mechanism. More recently the OVRO system has been made into a microwave spectrometer, examining typically 30 – 40 frequencies from 1 – 18 GHz with a time resolution of seconds. With this system Hurford (1983) found that some microwave precursors were characterized by narrow-band spectra with sharp high and low frequency cutoffs. He has interpreted these data in terms of gradual loop heating.

1.4.6 Non-Thermal Precursors

Long before SMM, it was argued that non-thermal processes occurred during the “buildup” phase of solar flares (Kane and Pick 1976) and in the absence of flares (Webb and Kundu 1978). Several preflare team members presented new evidence and theoretical arguments for non-thermal, non-flaring activity as seen in radio waves. Kosugi summarized a number of preflare activities observed at 17 GHz using the Nobeyama interferometer. He and his co-workers (Kai *et al.*, 1983) examined 25 pairs of bursts which occurred within 10 to 50 minutes of each other. These pairs were cospatial (in one dimension) to $< 50''$ in 12 out of 15 cases. In most cases, the prebursts were impulsive, and therefore were not likely to be signatures of gradual preflare heating. However, they also noted that in more than half of the cases, H α flaring started before the “preflare” burst, which argues in favor of preflare heating. They suggested three possible mechanisms for prebursts:

- A process related to the main energy release such as joule heating in current sheets.
- Pre-acceleration of electrons prior to the main acceleration.
- Manifestation of “leakage” of accelerated electrons.

They pointed out that the “leakage” mechanism is probably not consistent with the long time interval between bursts. Kosugi also showed evidence for statistical association in the number of type III (meter wave) bursts within minutes of prebursts at 17 GHz (Kosugi *et al.*, 1985). No spatial locations were available for the type III bursts. Finally, Jackson reported that a study of spatially located type III's observed at Culgoora showed a statistically significant tendency to occur an hour or so prior to large H α flares. If these associations between prebursts at 17 GHz, H α flares and type III's are valid, then the mechanism of pre-acceleration appears to be favored.

Harrison presented a model (Simnett and Harrison 1984) of precursors in which 10^2 - 10^3 keV protons heat a high coronal loop, destabilize the pressure balance and heat the chromospheric plasma to produce the precursor X-rays. The acceleration mechanism is a small shock, which primarily heats protons within a large-scale magnetic loop. The model is directed primarily at the situation where precursors are widely separated preceding a coronal mass ejection with or without a flare.

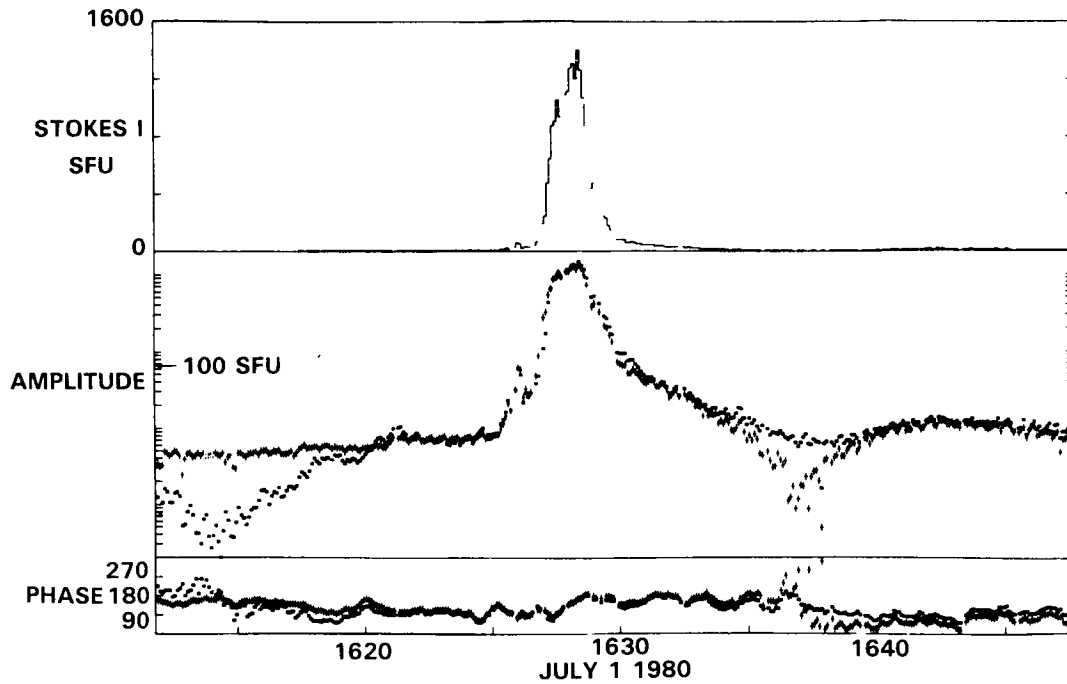


Figure 1.4.11a The July 1, 1980 flare time profiles at 10.6 GHz (Owens Valley Radio Observatory, (Hurford and Zirin 1982)) showing the "onset" signature of increasing I and decreasing V. The middle panels show the amplitudes of R and L (right and left circular polarizations); $V = (R-L)/V$.

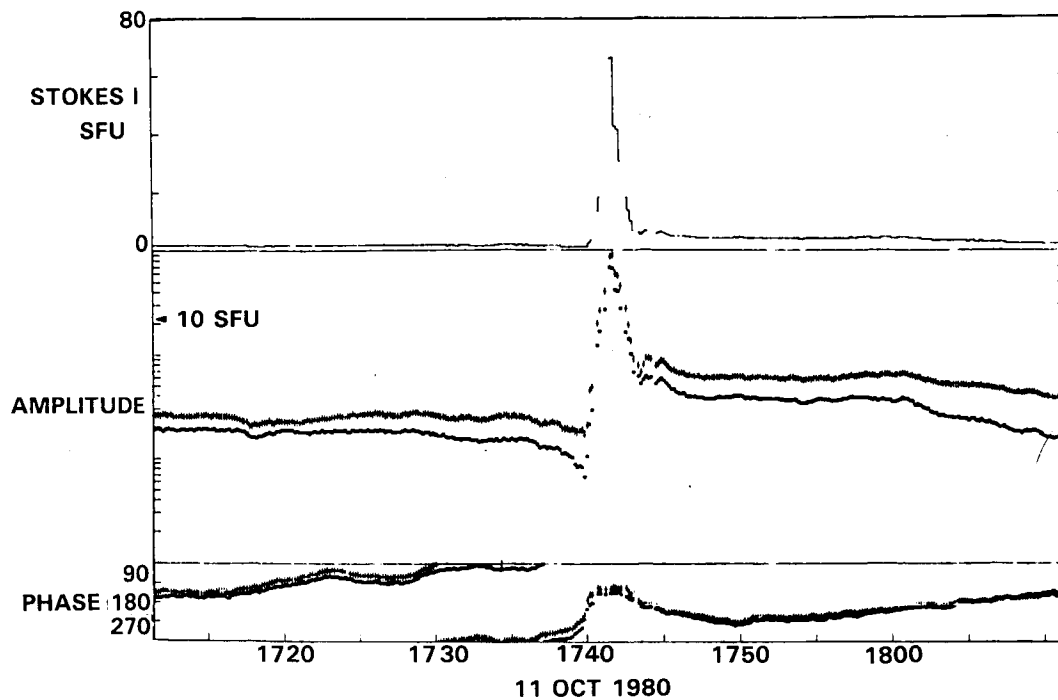


Figure 1.4.11b The Oct. 11, 1980 flare time profiles at 10.6 GHz (OVRO, Hurford and Zirin 1982).

There is evidence for electron acceleration in the absence of flares. Chiuderi-Drago pointed out that sometimes bright non-flaring sources ($T_b > 5 \times 10^6$ K) appear on microwave maps, and these sources may be explained (Chiuderi-Drago and Melozzi 1984) in terms of gyrosynchrotron emission from accelerated electrons trapped in coronal loops, where they may survive for $\sim 10^2$ sec. This is consistent with the lifetime of some precursors, and if continual acceleration occurs, the mechanism could explain some long-lived microwave sources. If the number of electrons is sufficiently high, then the gradual-rise-and-fall events commonly associated with filament disruptions (Webb *et al.*, 1976, Sheeley *et al.*, 1975), can be explained by a thermalization process (Webb and Kundu 1978) which follows the precursor acceleration.

1.4.7 Precursors of Coronal Mass Ejections

Although most of the SMM preflare data are for disk events, three coronal transient events on June 29 were well observed as region 2522/30 neared the limb.

All of these limb events were observed by HXIS and C/P (Harrison *et al.*, 1985) and the 02:33 and 18:22 events were also well observed by XRP and UVSP. These were possibly homologous events because the flares occurred in the same location and had similar X-ray profiles with GRF precursors and long flare decay times (Stewart, 1984; Woodgate *et al.*, 1984).

Figure 6.3.1a,b (Chapter 6) shows the HXIS flux profile for June 29 and the extrapolated C/P coronal transient onset times for two of the three events. The detailed HXIS data and their interpretation are presented in Chapter 6 and only summarized here.

A long-lived 160 MHz noise storm preceded the 02:33 flare but ended at 02:21 (Gary *et al.*, 1974). The flare was associated with two moving white-light loops whose height-time profile extrapolated back to the surface about 6-8 minutes before flare onset. The HXIS precursor began at about 02:10. Shine prepared Figure 1.4.12 which shows the preflare period 02:17–02:29 in Si IV and O IV rasters, as well as the flare itself (02:33–02:37). At the time of the first UVSP preflare rasters, the BCS, FCS and HXIS all recorded a brightening at the flare site at 02:19. Later, the point brightened again at $\sim 02:28$, but was not visible in X-rays. The onset of the Si IV/ O IV burst was at 02:33:56 and appeared as multi-pixel brightenings within $\sim 10''$ of the preflare UV brightenings.

The 10:40 UT event was not well observed by the C/P or UVSP, but a preflare He I “jet” was observed (Schmahl 1983). The white-light loop transient associated with the 18:22 flare had a projected surface start before 18:15 (Sime *et al.*, 1980, Harrison *et al.*, 1985). A small H α and X-ray flare occurred at 18:05 at a position slightly displaced from the later flare site. The UVSP observed a preflare OV loop and Fe XXI brightening (Poland *et al.*, 1982), and BCS anal-

ysis revealed turbulent line broadening up to 4 minutes before onset (Antonucci *et al.*, 1982).

The relationship between coronal mass ejection (CME's) transients and flares is far from clear, and it is fairly well established that one may have CME's without flares and vice versa.

However, Harrison *et al.* (1985) argue that the flare precursor and the mass ejection precursor may be one and the same. In Section 3 of Chapter 6 Harrison gives examples in which the X-ray precursor of the mass ejection may be very small, as large as a flare, or “a lone precursor”, without a following flare. At this stage of the analysis it is premature to assess the reality of the possible relationships among precursors of flares and CME's, but research along these lines may well provide a broader understanding of the role precursors play in the energy release process.

1.4.8 Short-Lived and Long-Lived HXIS Sources as Possible Precursors

Owing to its low background, particularly in its lowest energy band (3.5–5.5 keV), HXIS is capable of detecting very weak X-ray sources. The X-ray precursors reported by HXIS observers (Sections 1.4.3.3, 4 above) have been interpreted as thermal events, with temperatures $1-2 \times 10^7$ K. HXIS images often showed (Schadee *et al.*, 1983) short-lived sources (SLS) and long-lived sources (LLS) in the 3.5–5.5 keV band. The short-lived sources (lifetime less than or about 15m) appeared indistinguishable *per se* from HXIS precursors but did not always precede flares. The long-lived (hours-days) sources were of larger scale. Both had band-ratio temperatures of $\sim 10^7$ K.

In the context of our study, HXIS LLS's preceded two large flares with precursors, namely, May 21 20:55 and the June 22 flare discussed in Section 1.4.3.2. Although not part of this study, the May 21 X1 flare is one of the best analyzed SMM flares and is discussed elsewhere in this monograph. As in the June 22 case, it was preceded by a compression of pre-existing flux. See Section 3.5.4(iii), Harvey (1983). Discrete LLS's cospatial with the curving filament persisted for many hours on May 20 and 21. One source was located near the site of the EFR where the filament broadened then parted 10 minutes before impulsive onset.

Figures 1.4.13a (coarse FOV) and 1.4.13b (fine FOV) show accumulated HXIS images during 20 hours preceding a two-ribbon flare on June 21, 00:55. LLS's were frequently present, cospatial with the neutral line and filament curving from SE to WNW through the center of the FOV. LLS's occurred along the filament until its eruption before the flare of June 22, $\sim 13:04$. Even though the filament soon reformed, no further LLS's were observed after this event.

As evidenced by Figure 1.4.13, long-lived sources extend over a large area, often persisting for several hours.

June 29, 1980 2:34 GMT

M2 Flare on West Limb

pre-flare large rasters

Si IV 1402

O IV 1401

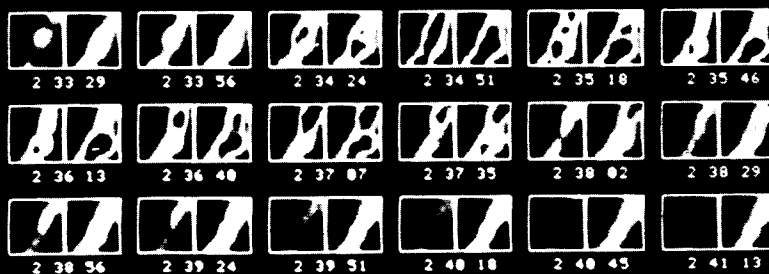


2:17 to 2:21 GMT

small rasters during flare

Si IV 1393A and O IV 1402A
each 7 x 7 raster covers 28" x 28"

Si IV O IV



pre-flare event



Figure 1.4.12 Preflare and flare images in Si IV and O IV (UVSP), 02:17-02:37, 29 June 1980.

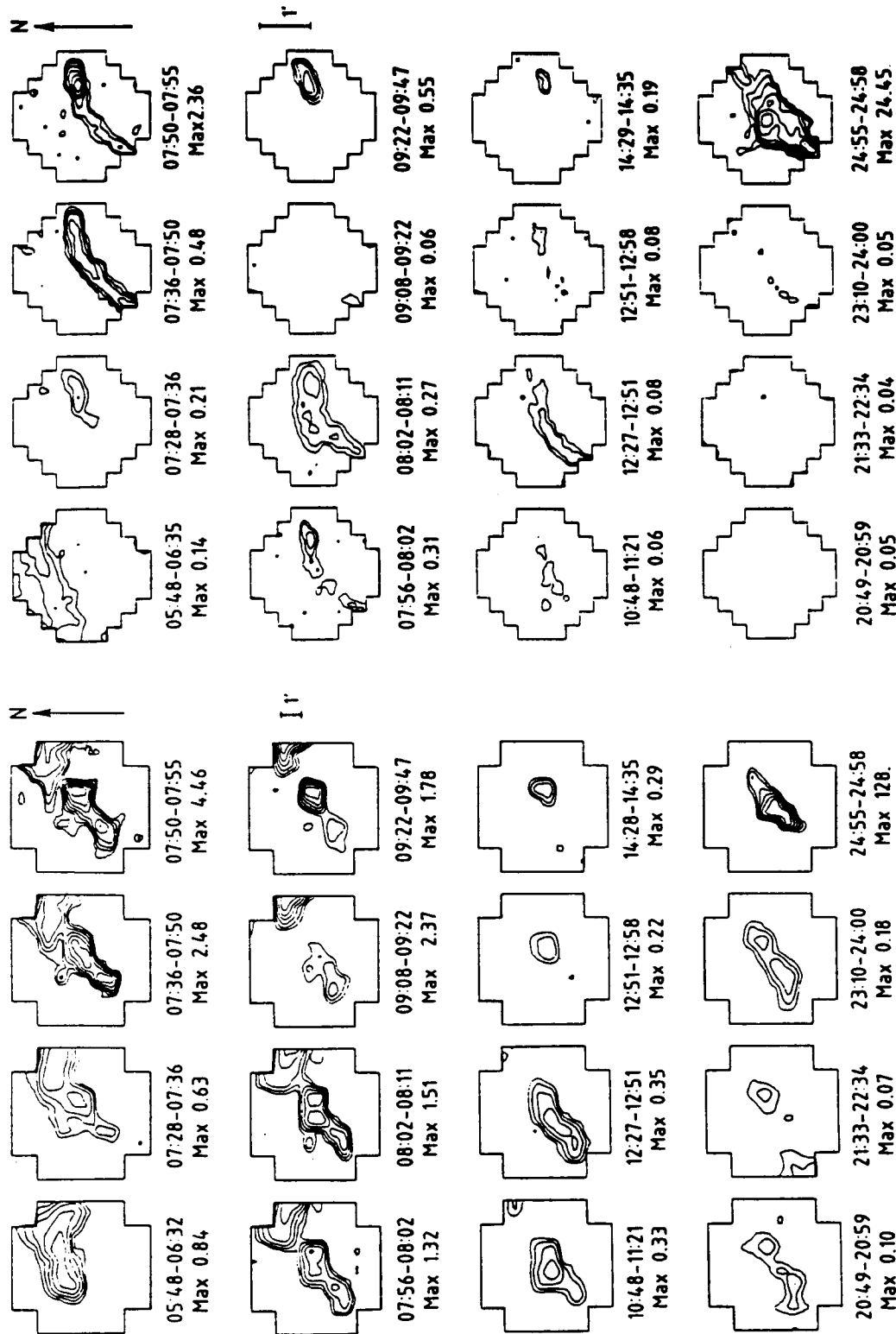


Figure 1.4.13 Long-Lived HXIS sources seen preflare June 22, 1980. Post-flare images do not show these sources. Coarse field-of-view maps are shown on the left and fine field-of-view maps are shown on the right.

The characteristics of LLS's are: durations of tens of minutes to hours; temperature $\sim 10^7$ K; and emission measures of $\sim 10^{46} \text{ cm}^{-3}$. They often show gradual intensity changes.

Most LLS's appear to result from activity along neutral lines. They may represent the high temperature tail of the thermalized plasma associated with filament activity as observed during Skylab (e.g., Webb *et al.*, 1976, Webb and Kundu 1978, Kahler 1977). The Skylab soft X-ray filament enhancements had emission measures an order of magnitude higher and temperatures of an order of magnitude lower than the HXIS LLS's.

If the LLS's originate beneath the filament, then the model of Kopp and Pneuman (1976), Van Tend-Kuperus (1978) and Hood and Priest (1980) may be applicable. In that model the convergence of magnetic flux towards the neutral line in the photosphere results in energy dissipation by reconnection below the filament in the corona. Interestingly, other observations (Athay *et al.*, 1984) show evidence of magnetic flux converging at the neutral line in the Martin region. They suggest a process of continuing reconnection. At this stage it is not clear whether the X-ray emission results from filament activation, from continuing reconnections, or both.

1.4.9 Summary: Are all the Blind Men Looking at the Same Elephant?

We have reported a variety of coronal manifestations of precursors or preheating for flares and have found that almost everyone with a telescope sees something before flares. Whether an all-encompassing scenario will ever be developed is not at all clear at present. The clearest example of preflare activity appears to be activated filaments and their manifestations, which presumably are signatures of a changing magnetic field. But we have seen two similar eruptions, one without any evidence of emerging flux (Kundu *et al.*, 1985) and the other with colliding poles (Simon *et al.*, 1984). While the reconnection of flux is generally agreed to be required to energize a flare, the emergence of flux from below (at least on short timescales and in compact regions) does not appear to be a necessary condition. In some cases the cancel-

ling of magnetic flux (Martin, 1984) by horizontal motions instead may provide the trigger (Priest, 1985).

We have found many similarities and some differences between these and previous observations. The similarities, besides the frequent involvement of filaments, include compact, multiple precursors which can occur both at and near (not at) the flare site, and the association between coronal sources and activity lower in the atmosphere (i.e., transition zone and chromosphere). Because of differences in instrumentation and improvement in multi-wavelength coverage with high time resolution, we have been able to identify several new aspects of preflare activity in the SMY data. These include the facts that: precursors were observed over a wide range of temperatures and heights; there were long-lived, hot ($> 10^7$ K) X-ray sources preceding some flares; and there was evidence for high energy phenomena, particularly electron and possibly proton acceleration before flares. The fairly rapid reformation of some filaments after their explosive eruption suggests that the photospheric boundary conditions remain unchanged, at least after some flares. Concerning filament-eruption flares, we saw suggestive examples in Section 1.4.3 of a flare exciting agent (at least as detected by its emission) first arising under the central portion of the filament.

Finally, our results leave us with several important questions. We have shown examples of preflare X-ray enhancements and small impulsive-like bursts. Are these signatures of a incremented instability, in which the flare "tries to start and fails" or are they signatures of a separate process that energizes the corona first with the flare following as a separate phenomenon?

Is the preflare gradual phase caused by the same mechanism as the postflare phase? Alternatively, does the gradual preheating occur through thermalization of an energetic population signified by nonthermal prebursts? Do microwave signatures signify changing coronal magnetic fields during the preflare hour, and (if so) what can we learn of the field strength and configurations? While the observational analysts continue to wrestle with the study of the vast SMM data store, the theoreticians must continue to synthesize and interpret these diverse phenomena in a consistent fashion.

1.5 REFERENCES

- Antonucci, E., Gabriel, A.H., and Dennis, B.R.: The Energetics of Chromospheric Evaporation in Solar Flares: *Astrophys. J.* 287, 1984, pp. 917-925.
- Antonucci, E., Gabriel, A.H., Acton, L.W., Culhane, J.L., Doyle, J.G., Leibacher, J.W., Machado, M.E., Orwig, L.E. and Rapley, C.G.: Impulsive Phase of Flares in Soft X-Ray Emission, *Solar Phys.* 78, 1982a, pp. 107-123.
- Antonucci, E., Wolfson, C.J., Rapley, C.G., Acton, L.W., Culhane, J.L. and Gabriel, A.H.: Solar Observations Using the Soft X-Ray Polychromator Experiment on SMM, *Proc. of the SMY International Workshop, Simferopol Moscow, IZMIRAN, 1*, 1982b, pp. 62-76.
- Athay, R. G., Jones, H. P., and Zirin, H.: Magnetic Shear I. Hale Region 16918. *Astrophys. J.* 288, 1984, pp. 363.
- Athay, R. G., White, O. R., Lites, B. W.; and Bruner, E. C. Jr.: Impulsive EUV Bursts Observed in C IV with OSO-8. *Solar Phys.* 66, 1980, pp. 357-370.
- Aydemir, A. and Barnes, D.: Sustained Self-Reversal in the Reversed Field Pinch, *Phys. Rev. Lett.* 52, 1985, pp. 930-935.
- Barnes, C.W. and Sturrock, P.A.: *Astrophys. J.* 174, 1972, p. 659.
- Bell, B. and Glazer, H.: Some Sunspot and Flare Statistics. *Smithsonian Contr. Astrophys.* 3, 1959, pp. 25-38.
- Bhatnagar, A.: H α Solar Observations During SERF and FBS Intervals of April 6-12 and May 22-28, 1980, *Proc. of the SMY International Workshop, Simferopol, 1*, 1981, pp. 202-214.
- Bhattacharjee, A., Brunel, P. and Tajima, T.: Magnetic Reconnection Driven by the Coalescence Instability, *Phys. Fluids* 26, 1983, pp. 3332-3337.
- Birn, J. and Schindler K.: Two-Ribbon flares: Magnetostatic Equilibria, Ch. 6 of *Solar Flare MHD* (ed. E.R. Priest), Gordon and Breach (1981).
- Birn, J., Goldstein, H., and Schindler, K.: A Theory of the Onset of Solar Eruptive Processes., *Solar Phys.* 57, 1978, pp. 81-101.
- Biskamp, D.: Effect of Secondary Tearing Instability on the Coalescence of Magnetic Islands, *Phys. Letters* 871, 1982a, pp. 357-360.
- Biskamp, D.: Dynamics of a Resistive Sheet Pinch, *Z. Naturforsch* 37a, 1982b, pp. 840-847.
- Biskamp, D.: Resistive MHD Processes, *Physica Scripta*, T22, 1982c, p. 405.
- Born, R.: First Phase of Active Regions and their Relation to the Chromospheric Network, *Solar Phys.* 38, 1974, pp. 379-388.
- Brants, J.J., Cram, L.E., Zwaan, C.: An Emerging Active Region: Some Preliminary Results. *The Physics of Sunspots*, L.E. Cram and J.H. Thomas (eds.), Sacramento Peak Workshop, pp. 60-63.
- Brants, J.J.: High-Resolution Spectroscopy of Active Regions II: Line Profile Interpretation Applied to an Emerging Flux Region. *Solar Phys.* 95, 1985, pp. 15-36.
- Bray, R.J., and Loughhead, R.E.: *Sunspots*. Chapman and Hall, London, 1964, pp. 226-236.
- Browning, P.K. and Priest, E.R.: Magnetic Nonequilibrium of Buoyant Flux Tubes, *Solar Phys.* 92, 1984, pp. 173-188.
- Bruzek, A.: On Arch-Filament Systems in Spotgroups, *Solar Phys.* 2, 1967, pp. 451-461.
- Bruzek, A.: On Small-Scale Mass Motion Associated with Flares. *Mass Motions in Solar Flares and Related Phenomena*, Y. Ohman (ed.), Nobel Symposium 9, John Wiley & Sons, 1968, pp. 67-70.
- Bruzek, A.: Motions in Arch Filament Systems, *Solar Phys.* 8, 1969, 29-36.
- Bruzek, A., and DeMastus, H.L.: Flare-Associated Coronal Expansion Phenomena, *Solar Phys.* 12, 1970, pp. 447-457.
- Bruzek, A.: Some Observational Results on Moustaches, *Solar Phys.* 26, 1972, pp. 94-107.
- Bumba, V. and Obridko, V.N.: "Bartels" Active Longitudes, Sector Boundaries and Flare Activity, *Solar Phys.* 6, 1969, pp. 104-110.
- Bumba, V.: Radial Motions in Small and Young Sunspots. *Bull. Astron. Inst. Czech.* 18, pp. 238-243.
- Bumba, V. and Howard, R.: A Study of the Development of Active Regions on the Sun, *Astrophys. J.* 141, 1981, pp. 413-470.
- Canfield, R.C., Priest, E.R., and Rust, D.M.: A Model for the Solar Flare, Flare Related Magnetic Field Dynamics, *Proceedings of a Conference, High Altitude Observatory, CO.*, 1974, pp. 361-371.
- Canfield, R.C. and Fisher, R.R.: Magnetic Field Reconnection in the Flare of 18:28 UT 1975 August 10, *Astrophys. J. Lett.* 210, 1976, pp. L149-L151.
- Cargill, P.J. and Priest, E.R.: Slow-Shock Heating and the Kopp-Pneuman Model for 'Post'-Flare Loops, *Solar Phys.* 76, 1982, pp. 357-375.
- Cargill, P.J., Migliuolo, A. and Hood, A.W.: Activation of Solar Flares, *Proc. Varenna Workshop on Plasma Astrophysics*, 1984.
- Cargill, P.J., Hood, A.W. and Migliuolo, S.: MHD Stability of Line-Tied Coronal Arcades, III Necessary and Sufficient Conditions, *Astrophys. J.*, submitted.
- Cheng, C.-C., Bruner, E. C., Tandberg-Hanssen, E., Woodgate, B. E., Shine, R. A., Kenny, P. J., Henze, W., and Poletto, G.: Observations of Solar Flare Transition Zone Plasmas from the Solar Maximum Mission. *Astrophys. J.* 253, 1982, pp. 353-366.
- Chiuderi Drago, F. and Melozzi, M.: Non-Thermal Radio Sources in Solar Active Regions *Astron. Astrophys.* 131, 1984, pp. 103-110.
- Cliver, E.W., Forrest, D.J., McGuire, R.E. and von Rosenvinge, T.T.: Nuclear Gamma Rays and Interplanetary Proton Events, in the 18th International Cosmic Ray conference, *Late Papers vol.*, eds., Durgaprasad *et al.*, 1984, Tata Institute, Colaba, Bombay, India.
- Culhane, J.L. and Phillips, K.J.H.: Solar X-Ray Bursts at Energies Less than 10 keV Observed with OSO-4, *Solar Phys.*, 11, 1970, pp. 117-144.
- de Jager, C., Machado, M.E., Schadee, A., Strong, K.T., Svestka, Z., Woodgate, B.E. and van Tend, W.: The Queen's Flare: Its Structure and Development; Precursors, Pre-Flare Brightenings, and Aftermaths, *Solar Phys.* 84, 1983, pp. 205-235.
- deLoach, A. C., Hagyard, M. J., Rabin, D., Moore, R. L., Smith, J. B., Jr.; West, E. A.; and Tandberg-Hanssen, E.: Photospheric Electric Current and Transition Region Brightness within an Active Region. *Solar Phys.* 91, 1984, pp. 235-242.
- Duijveman, A., Hoyng, P. and Machado, M.E.: X-Ray Imaging of Three Flares During the Impulsive Phase, *Solar Phys.* 81, 1982a, pp. 137-157.
- Duijveman, A., Somov, B.V. and Spektor, A.R.: Evolution of a Flaring Loop after Injection of Energetic Electrons *Solar Phys.* 58, 1982b, pp. 257-273.
- Dulk, G.A. and Dennis, B.R.: Microwaves and Hard X-Rays from

- Solar Flares: Multithermal and Nonthermal Interpretations, *Astrophys. J.* **260**, 1982, pp. 844-875.
- Dunn, J.M. and Martin, S.F.: An Attempt to Identify Flare Precursor Mass Motions in Real Time, *Bull. Am. Astr. Soc.* **12**, 1980, p. 904.
- Dwivedi, B.N., Hudson, H.S., Kane, S.R., and Svestka, Z.: Haand Hard X-Ray Development in Two-Ribbon Flares, *Solar Phys.* **90**, 1984, pp. 331-342.
- Einaudi, G. and Van Hoven G.: Stability of Diffuse Linear Pinch with Axial Boundaries, *Phys. Fluids* **24**, 1981, pp. 1092-1096.
- Enome, S., Shibasaki, K., Takayanagi, T., and Takata, S., Atlas of Solar Bursts for 1980, Toyokawa Obs., WDC-C2, 1981.
- Finn, J.M. and Kaw, P.K.: Coalescence Instability of Magnetic Islands, *Phys. Fluids* **20**, 1977, pp. 72-79.
- Forbes, T.G. and Priest, E.R.: Numerical Study of Line-Tied Magnetic Reconnection, *Solar Phys.* **81**, 1982, pp. 303-324.
- Forbes, T.G. and Priest, E.R.: A Numerical Experiment Relevant to LineTied Reconnection in Two-Ribbon Flares, *Solar Phys.* **34**, 1983a, pp. 169-188.
- Forbes, T.G. and Priest, E.R.: Mass Upflows in 'Post'-Flare Loops, *Solar Phys.* **88**, 1983b, pp. 211-218.
- Forbes, T.G. and Priest, E.R.: Numerical Simulation of Reconnection in an Emerging Magnetic Flux Region, *Solar Phys.* **94**, 1984, pp. 315-340.
- Forbes, T.G. and Priest, E.R.: Reconnection in Solar Flares, *Proc. Solar Terrestrial Theory Workshop*, Coolfont (ed. B.U.O. Sonnerup).
- Frazier, E.N.: The Magnetic Structure of Arch-Filament Systems, *Solar Phys.* **26**, 1972, pp. 130-141.
- Furth, H.P., Killeen, J. and Rosenbluth, M.N.: Finite-resistivity Instabilities of a Sheet Pinch, *Phys. Fluids* **6**, 1963, pp. 459-484.
- Gabriel, A.H. and 14 co-authors: Observations of the Limb Solar Flare on 1980 April 30 with the SMM X-Ray Polychromator, *Astrophys. J.* **244**, 1981, pp. L147-L151.
- Gaizauskas, V.: Preflare Activations of Filaments Located Along Inversion Lines of Magnetic Polarity, *Proc. Kunming Workshop*, 1984 (in press).
- Gaizauskas, V.: The Relation of Solar Flares to the Evolution and Proper Motions of Magnetic Fields, *Adv. Space Res.* (Eds. Svestka, Rust and Dryer) **2**, 1983, pp. 11-30.
- Gaizauskas, V., Harvey, K.L., Harvey, J.W., Zwaan, C.: Large-Scale Patterns Formed by Solar Active Regions During the Ascending Phase of Cycle 21, *Astrophys. J.*, **265**, 1983, pp. 1056-1065.
- Gaizauskas, V. and McIntosh, P.S.: On the Flare-Effectiveness of Recurrent Patterns of Magnetic Fields, *Proc. Workshop on Solar Terrestrial Predictions*, Meudon, 1984, submitted.
- Gary, D.: Radio Emission from Solar and Stellar Coronae, Ph.D. Thesis, 1982, Univ. of Colorado (University Microfilms).
- Gary, D., Dulk, G.A., Illing, R., Sawyer, C., Wagner, W.J., McLean, D.J., and Hildner, E.: Type II Bursts, Shock Waves and Coronal Transients: The Event of 1980 June 29, 0233 UT, *Astron. Astrophys.* **134**, 1984, pp. 222-233.
- Giovannelli, R.G.: The Relations between Eruptions and Sunspots, *Astrophys. J.* **89**, 1939, pp. 555-567.
- Glackin, D.L.: Emerging Flux Region, *Solar Phys.* **43**, 1975, pp. 317-326.
- Gosling, J.T., Hildner, E., MacQueen, R.M., Munro, R.H., Poland, A.I., and Ross, C.L.: The Speeds of Coronal Mass Ejection Events, *Solar Phys.* **48**, 1976, pp. 389-397.
- Hagyard, M. J., Cumings, N. P., West, E. A., and Smith, J. E.: The MSFC Vector Magnetograph, *Solar Phys.* **80**, 1982, pp. 33-51.
- Hagyard, M.J., Smith, J.B., Jr., Teuber, D., and West, E.A.: A Quantative Study Relating Observed Shear in Photospheric Magnetic Fields to Repeated Flaring, *Solar Phys.* **91**, 1984, pp. 115-126.
- Hagyard, M. J.; West, E. A.; and Smith, J. B., Jr.: Electric Currents in Active Regions. *Proceedings of the Kunming Workshop on Solar Physics and InterPlanetary travelling Phenomena*, Kunming, People's Republic of China, 1984, in press.
- Harrison, R., Waggett, P., Bentley, R., Phillips, K.J.H., Bruner, M., Dryer, M. and Simnett, G.M: *Solar Phys.* 1985, in press.
- Harvey, J., Gillespie, B., Miedaner, P., Slaughter, C.: Synoptic Solar Magnetic Field Maps for the Interval Including Carrington Rotations 1601-1680, May 5, 1973 - April 26, 1979. World Data Center A, Report UAG-77, 1980, (Boulder, CO).
- Harvey, J.W.: Flare Build-up: 21 May 1980, *Adv. Space Res.* **2**, 1983, pp. 31-37.
- Harvey, K.L. and Martin, S.F.: Ephemeral Active Regions, *Solar Phys.* **32**, 1973, pp. 389-402.
- Harvey, K.L. and Harvey, J.W.: Observations of Moving Magnetic Features near Sunspots, *Solar Phys.* **28**, 1973, pp. 61-71.
- Harvey, K. L., and Harvey, J. W.: A Study of the Magnetic and Velocity Fields in an Active Region, *Solar Phys.* **47**, 1976, pp. 233-246.
- Heyvaerts, J., Priest, E.R. and Rust, D.M.: An Emerging Flux Model for the Solar Flare Phenomenon, *Astrophys. J.* **216**, 1977, pp. 123-137.
- Heyvaerts, J., Lasry, J.M., Schatsman, M. and Witomsky, P., Blowing up of Two-Dimensional Magnetohydrostatic Equilibria by an Increase of Electrical Current or Pressure, *Astron. Astrophys.* **111**, 1982, pp. 104-112.
- Heyvaerts, J. and Priest, E.R.: Coronal Heating by Reconnection in DC Current Systems: a Theory Based on Taylor's Hypothesis, *Astron. Astrophys.* **137**, 1984, pp. 63-68.
- Hong Qin-Fang; Ding You-Ji; and Luan Di: The Rapidly Emerging Sunspot Group in SESC 2372 Region in April 1980. *Acta Astronomica Sinica* **23**, 1982, pp. 327-334.
- Hood, A.W. and Priest, E.R.: Kink Instability of Coronal Loops as the Cause of Solar Flares, *Solar Phys.* **64**, 1979, pp. 303-321.
- Hood, A.W. and Priest, E.R.: The Equilibrium of Solar Coronal Magnetic Loops, *Astron. Astrophys.* **77**, 1979, pp. 233-251.
- Hood, A.W. and Priest, E.R.: Magnetic Instability of Coronal Arcades as the Origin of Two-Ribbon Flares, *Solar Phys.* **66**, 1980, pp. 113-134.
- Hood, A.W. and Priest, E.L.: Critical Condition for Magnetic Instabilities in Force-Free Coronal Loops, *Geophys. Astrophys. Fluid Dynamics* **17**, 1981, pp. 297-318.
- Hood, A.W.: Magnetic Stability of Coronal Arcades Relevant to Two-Ribbon Flares, *Solar Phys.* **87**, 1983a, pp. 279-299.
- Hood, A.W.: Stability of Magnetohydrostatic Atmospheres, *Solar Phys.* **89** 1983b, pp. 235-242.
- Hood, A.W.: An Energy Method for the Stability of Solar Magnetohydrostatic Atmospheres, *Geophys. Astrophys. Fluid Dynamics* **28**, 1984a, pp. 223-241.
- Hood, A.W.: Stability of Magnetic Fields Relevant to Two-Ribbon Flares, *Adv. in Space Research*, 1984b, in press.

- Hoyng, P., Marsh, K., Zirin, H., and Dennis, B.R.: Microwave and Hard X-ray Imaging of a Solar Flare on 1980 November 5, *Astrophys. J.* 268, 1983, pp. 865-879.
- Hoyng, P. and 23 co-authors: Hard X-Ray Imaging of Two Flares in Active Region 2372, *Astrophys. J.* 244, 1981, pp. L153-L156.
- Hoyng, P., Duijveman, A., Machado, M.E., Rust, D.M., Svestka, Z., Boelee, A., de Jager, C., Frost, K.J., Lafleur, H., Simnett, G.M., van Beek, H.F., and Woodgate, B.E.: Origin and Location of the Hard X-ray Emission in a Two-Ribbon Flare, *Astrophys. J.* 246, 1981, pp. L155-L159.
- Hurford, G.J. and Zirin, H.: Interferometric Observations of Solar Flare Precursors at 10.6 GHz, Technical Report AFGL 3, TR-82-0117, March 1982.
- Hurford, G.J.: The Owens Valley Frequency-Agile Interferometer, Technical Report AFGL-TR-83-0108, March 1983.
- Jackson, R. and Hildner, E.: Forerunners: Outer Rims of Solar Coronal Transients, *Solar Phys.* 60, 1978, pp. 155-170.
- Jackson, B.V.: Forerunners: Early Coronal Manifestations of Solar Mass Ejection Events, *Solar Phys.* 73, pp. 133-144.
- Jackson, B.V. and Sheridan, K.V.: Evidence for a Peak in the Number of Isolated Type III Bursts prior to Large Solar Flares, *Proc. Astron. Soc. Aust.* 3, 1979, pp. 383-386.
- Kahler, J.N. and Buratti, B.D.: Preflare X-Ray Morphology of Active Regions Observed with the AS&E Telescope on Skylab, *Solar Phys.* 47, 1976, pp. 157-165.
- Kahler, S.W.: Preflare Characteristics of Active Regions Observed in Soft X-rays, *Solar Phys.* 62, 1979, pp. 347-357.
- Kahler, S.: The Morphological and Statistical Properties of Solar X-Ray Events with Long Decay Times, *Astrophys. J.*, 214, 1977, pp. 891-897.
- Kai, K., Nakajima, H. and Kosugi, T.: Radio Observations of Small Activity Prior to Main Energy Release, *P.A.S.J.* 35, 1983, pp. 285-297.
- Kane, S.R. and Pick, M.: Non-thermal Processes During the 'Build-up' Phase of Solar Flares and in the Absence of Flares, *Solar Phys.* 47, 1976, pp. 293-304.
- Karpen, J. and Boris, 1985, submitted
- Kawaguchi, I. and Kitai, R.: The Velocity Field Associated with the Birth of Sunspots, *Solar Phys.* 45, 1976, pp. 125-135.
- Kiepenheuer, K.O.: Solar Activity. The Sun, G.P. Kuiper (ed.), University of Chicago Press, 1953, pp. 348-352.
- Kopp, R.A. and Pneuman, G.W.: Magnetic Reconnection in the Corona and the Loop Prominence Phenomenon, *Solar Phys.* 50, 1976, pp. 85-98.
- Kosugi, T., Kai, K. and Nakajima, H.: Statistical Study of Type III Burst Activity Before Flares, to be submitted, 1985.
- Kosugi, T. and Shiomi, Y., Solar Radio Activities, Nobeyama Solar Radio Observatory of the Tokyo Astron. Observatory, February 1983.
- Krall, K. R., Smith, J. B., Jr., Hagyard, M. J., West, E. A. and Cumings, N.P.: Vector Magnetic Field Evolution, Energy Storage, and Associated Photospheric Velocity Shear within a Flare-Productive Active Region. *Solar Phys.* 79, pp. 59-75.
- Kundu, M.R., Schmahl, E.J., Velusamy, T. and Vlahos, L.: Radio Imaging of Solar Flares Using the Very Large Array: New Insight into Flare Process, *Astron. Astrophys.* 108, 1982, pp. 188-194.
- Kundu, M., Gaizauskas, V., Woodgate, B., Schmahl, E.J., Jones, H., and Shine, R. A Study of Flare Buildup from Simultaneous Observations in Microwave, H α and UV Wavelengths, *Astrophys. J. Suppl.* 57, 1985, pp. 621-530.
- Kundu, M.R., Solar Flare Observations at Centimeter Wavelengths Using the VLA, Proc. of the SMY International Workshop, Simferopol, Moskow, IZMIRAN, 1, 1981, pp. 124.
- Kundu, M.R. and Shevgaonkar, R.K.: VLA Observations of a Pre-Flare Solar Active Region and a Flare at 2, 6 and 20 Centimeter Wavelengths, *Astrophys. J.* 291, 1985, pp. 860-864.
- Kuperus, M. and van Tend, W.: The Eruption of Active Region Filaments and its Relation to the Triggering of a Solar Flare, *Solar Phys.* 71, 1981, pp. 125-139.
- Lang, K.R.: High Resolution Interferometry of the Sun at 3.7 cm Wavelength, *Solar Phys.* 36, 1974, pp. 351-367.
- Lang, K.R.: in Solar Terrestrial Prediction Proceedings III, Solar Activity Predictions, 1979 (ed. R.F. Donnelly).
- Levine, R.H.: EUV Structure of a Small Flare, *Solar Phys.* 56, 1978, pp. 185-203.
- Liggett, M. and Zirin, H.: Emerging Flux in Active Regions. *Solar Phys.* 1984, in press.
- Lites, B. W.; and Hansen, E. R.: Ultraviolet Brightenings in Active Regions as Observed from OSO-8. *Solar Phys.* 55, 1977, pp. 347-358.
- Low, B. C.: Evolving Force-Free Magnetic Fields. I. The Development of the Preflare Stage. *Astrophys. J.*, 212, 1977, pp. 234-242.
- Low, B. C.: Evolving Force-Free magnetic Fields. II. Stability of Field Configurations and the Accompanying Motion of the Medium. *Astrophys. J.* 217, 1977, pp. 988-998.
- MacQueen, R.M. and Fisher, R.R.: The Kinematics of Solar Inner Coronal Transients, *Solar Phys.*, 89, 1983, pp. 89-102.
- Machado, M. E., Somov, B. V., Rovira, M. G. and De Jager, C.: The Flares of April 1980. *Solar Phys.* 85, 1983, pp. 157-184.
- Machado, M.E., Duijveman, A. and Dennis, B.R.: Spatial and Temporal Evolution of Soft and Hard X-Ray Emission in a Solar flare. *Solar Phys.* 79, 1982, pp. 85-106.
- Machado, M.E., Somov, B.V., Rovira, M.R., and de Jager, C.: The Flares of April 1980: A Case for Flares Caused by Interacting Field Structures, *Solar Phys.* 85, 1983, pp. 157-184.
- Malherbe, J.M., Simon, G., Mein, P., Mein, N., Schmieder, B., and Vial, J.C.: Preflare Heating of Filaments, *Adv. Space Res.*, (eds. Svestka, Rust and Dryer) 2, 1983, pp. 53-56.
- Malherbe, J.M., Mein, P. and Schmieder, B: Mass Motions in a Quiescent Filament, in *Advances in Space Research*, (eds., Z. Svesta, D.M. Rust and M. Dryer) 2, 1983, pp. 57-60.
- Malherbe, J.M. and Priest, E.R.: Current Sheet Models for Solar Prominences, I, Magnetohydrostatics of Support and Evolution through Quasi-Static Models, *Astron. Astrophys.* 123, 1983, pp. 80-88.
- Malherbe, J.M., Priest, E.R., Forbes, T.G. and Heyvaerts, J.: Current Sheet Models for Solar Prominences, II, Energetics and Condensation Process, *Astrophys. J.* 127, 1983, pp. 153-160.
- Manheimer, W. and Boris, J.P.: Comments Plasma Phys. Conf. Fusion 3, 15, 1977.
- Mariska, J.T., Boris, J.P., Oran, E.S., Young, T.R., Jr., and Doschek, G.A., *Astrophys. J.* 255, 1982, p. 783.
- Marsh, K.A.: Ephemeral Region Flares and the Diffusion of the Network. *Solar Phys.* 59, 1978, pp. 105-113.
- Marsh, K.A., Hurford, G.J., Zirin, H., Dulk, G.A., Dennis, B.R., Frost, K.J. and Orwig, L.E.: Properties of Solar Flare Elec-

- trons Deduced from Hard X-Ray and Spatially Resolved Microwave Observations, *Astrophys. J.* 251, pp. 797-804.
- Martens, P.C.H. and Kuperus, M.: Resonant Electrodynamical Heating and the Thermal Stability of Coronal Loops, *Astron. Astrophys.* 114, 1982, pp. 324-327.
- Martens, P.C.H., Van den Oord, G.H.J. and Hoyng, P.: Observations of Steady Anomalous Magnetic Heating in Thin Current Sheets, *Solar Physics*, 96, 1985, pp. 253-274.
- Martin, S.F. and Ramsey, H.E.: 1972, in *Solar Activity Observations and Predictions* (eds. P. McIntosh and M. Dryer), MIT Press, Cambridge, MA, pp. 371-388.
- Martin, S.F.: Preflare Conditions, Changes and Events, *Solar Phys.* 68, 1980, pp. 217-236.
- Martin, S.F., Dezso, L., Antalova, A., Jucera, A., and Harvey, K.L.: Emerging Magnetic Flux, Flares and Filaments - FBS Interval 16-23 June 1980 (eds. Z. Svestka, D. Rust and M. Dryer) *Adv. Space Res.* 2, 1983, pp. 39-51.
- Martin, S.F.: Early Signs of New Active Regions, *Bull. American Astron. Soc.* 15, 1983, p. 971.
- Martin, S.F.: Dynamic Signatures of Quiet Sun Magnetic Fields. Small-Scale Dynamical Processes, Sacramento Peak Workshop, 1984, in press.
- Martres, M. -J., Michard, R., Soru-Iscovisci, I. and Tsap, T. T.: Etude de la Localisation des Eruptions dans la Structure Magnetique Evolutive des Regions Actives Solaires. *Solar Phys.* 5, 1968, pp. 187-206.
- Martres, M. J., Soru-Escout, I., and Rayrole, J.: An Attempt to Associate Observed Photospheric Motions with the Magnetic Field Structure and Flare Occurrence in an Active Region. *Solar Magnetic Fields*, IAU Symposium No. 43, R. Howard (ed.), D. Reidel Publishing Co., Holland, 1971, pp. 435-442.
- Martres, M. -J., Soru-Escout, I., and Rayrole, J.: Relationship between Some Photospheric Motions and the Evolution of Active Centres. *Solar Phys.* 32, 1973, pp. 365-378.
- Martres, M. -J., Rayrole, J., Ribes, E., Semel, M. and Soru-Escout, I.: On the Importance of Photospheric Velocities in Relation to Flares. Flare Related Magnetic Field Dynamics, Proceedings of a Conference, High Altitude Observatory, Boulder, Co., 1974, pp. 333-352.
- Martres, M. -J. and Soru-Escout, I.: The Relation of Flares to 'Newly Emerging Flux' and 'Evolving Magnetic Features.' *Solar Phys.*, 53, 1977, pp. 225-231.
- McConnell, D. and Kundu, M.R.: VLA Observations of Fine Structures in a Solar Active Region at 6 Centimeter Wavelength, *Astrophys. J.* 279, 1984, pp. 421-426.
- McIntosh, P.S.: The Birth and Evolution of Sunspots: Observations, *The Physics of Sunspots*, L.E. Cram and J.H. Thomas (eds.), Sacramento Peak Workshop, 1981, pp. 7-57.
- McKenna-Lawlor, S.M.P. and Richter A.K.L.: Physical Interpretation of Interdisciplinary Solar/Interplanetary Observations Relevant to the 27-29 June 1980 SMOY/STIP Event No. 5, in *Advances Space Res.* (eds., Z. Svestka, D.M. Rust and M. Dryer), 2, 1982, pp. 239-251.
- Melville, J.P., Hood, A.W. and Priest, E.R.: Magnetic Equilibrium in Coronal Arcades, *Solar Phys.* 87, 1983, pp. 301-307.
- Melville, J.P., Hood, A.W. and Priest, E.R.: Magnetohydrostatic Structures in the Corona, *Solar Phys.* 92, 1984, pp. 15- .
- Migiulolo, S. and Cargill, P.J.: MHD Stability of Line-Tied Coronal Arcades, I, *Astrophys. J.* 271, 1983, pp. 820-831.
- Migiulolo, S., Cargill, P.J. and Hood, A.W.: MHD Stability of Line-Tied Coronal Arcades, II, Shearless Magnetic Fields, *Astrophys. J.* 281, 1984, pp. 413-418.
- Milne, A. and Priest, E.R.: Internal Structure of Reconnecting Current Sheets and the Emerging Flux Model for Solar Flares, *Solar Phys.* 72, 1981, pp. 157-182.
- Mok, Y. and Van Hoven, G.: Resistive Magnetic Tearing in a Finite Length Pinch, *Phys. Fluids* 25, 1982, pp. 636-642.
- Molodensky, M. M.: Equilibrium and Stability of Force-Free Magnetic Field. *Solar Phys.* 39, 1974, pp. 393-404.
- Moore, R.L., Hurford, G.J., Jones, H. and Kane, S.R.: Magnetic Changes Observed in a Flare, *Astrophys. J.* 276, 1984, pp. 379-390.
- Moreton, G. E. and Severny, A. B.: Magnetic Fields and Flares in the Region CMP 20 September 1963. *Solar Phys.* 3, 1968, pp. 282-297.
- Mosher, J.M. and Acton, L.W.: X-rays, Filament Activity and Flare Prediction, *Solar Phys.* 66, 1980, pp. 105-111.
- Mouradian, Z., Martres, M. J., and Soru-Escout, I.: The Emerging Magnetic Flux and the Elementary Eruptive Phenomenon, *Solar Phys.* 87, 1983, pp. 309-328.
- Nagy, I.: Sunspot Proper Motions in the Western Part of Hale Region 16864 (May 25029, 1980), *Publ. Debrecen Obs.*, 5, 1983, pp. 107-116.
- Nakagawa, Y. and Raadu, M. A.: On Practical Representation of Magnetic Field, *Solar Phys.* 25, 1972, pp. 127-135.
- Neidig, D.F. and Cliver, E.W.: A Catalog of Solar White-Light Flares (1859-1982), Including their Statistical Properties and Associated Emissions, AFGL-TR-83-0257, 1983, Hanscom AFB, MA.
- van den Oord, B.V.D., Martens P.C.H. and Hoyng, P.: HXIS Observations of the Thermal Evolution of the Coronal Loop of November 5/6, 1980, *Solar Phys.*, 1984, (to be submitted).
- Parker, E.N.: *Cosmical Magnetic Fields*, Oxford University Press, 1979.
- Parker, E.N.: Magnetic Reconnection and Magnetic Activity, *Magnetic Reconnection in Space and Laboratory Plasmas* (ed. E. Hones) A.G.U. Geomonomograph Series, 1984, pp. 32-38.
- Patty, S. R. and Hagyard, M. J.: Delta-Configurations: Flare Activity and Magnetic Field Structure, *Solar Phys.*, 1984, submitted.
- Petschek, H.E.: Magnetic Field Annihilation, *AAS-NASA Symp. on Phys. of Solar Flares*, NASA SP-1954, pp. 425-539.
- Petrasso, R.D., Kahler, S.W., Krieger, A.S., Silk, J.K. and Vaiana, G.S.: The Location of the Site of Energy Release in a Solar X-Ray Subflare, *Astrophys. J. Letters* L199, 1975, pp. L127-L130.
- Poland, A.I., Machado, M.E., Wolfson, C.J., Frost, K.J., Woodgate, B.E., Shine, R.A., Kenny, P.J., Cheng, C.-C., Tandberg-Hanssen, E.A., Bruner, E.C., Henze, W.: The Impulsive and Gradual Phases of a Solar Limb Flare as Observed from the Solar Maximum Mission Satellite, *Solar Phys.* 78, 1982, pp. 201-213.
- Porter, J. G., Toomre, J. and Gebbie, K. B.: Frequent UV Brightenings Observed in a Solar Active Region with SMM, *Astrophys. J.* 283, 1984, pp. 879-886.
- Priest, E.R. and Milne, A.M.: Force-Free Magnetic Arcades Relevant to Two-Ribbon Flares, *Solar Phys.* 65, 1980, pp. 315-346.
- Priest, E.R.: *Solar Flare Magnetohydrodynamics*, Gordon and

- Breach, 1981a.
- Priest, E.R.: Flare Theories, Proc. 3rd European Solar Meeting (ed. C. Jordan) 1981b, pp. 203-232.
- Priest, E.R.: Magnetic Reconnection at the Sun, Magnetic Reconnection in Space and Laboratory Plasmas (ed. E. Hones) A.G.U. Geomonograph, 1984a, pp. 63-79.
- Priest, E.R.: The MHD of Current Sheets, Rep. Prog. Phys. 1985, 48, No. 7.
- Priest, E.R.: Small-Scale Reconnection, Proc. ESA Meeting on SOHO and CLUSTER, Garmisch, 1985a.
- Priest, E.F.: Magnetohydrodynamic Theories of Solar Flares, Solar Phys., in press, 1985b.
- Pritchett, P.L. and Wu, C.C.: Coalescence of Magnetic Islands, Phys. Fluids 22, 1979, pp. 2140-2146.
- Raadu, M.A.: Suppression of Kink Instability for Magnetic Flux Ropes in the Chromosphere, Solar Phys. 22, 1972, pp. 425-433.
- Rabin, D. M.; Moore, R. L.; and Hagyard, M. J.: A Case for Submergence of Magnetic Flux in a Solar Active Region. Astrophys. J. 287, 1984, pp. 404-411.
- Rabin, D. and Moore, R. L.: Heating the Sun's Lower Transition Region with Fine-Scale Currents. Astrophys. J. 285, 1984, pp. 359-367.
- Ray, A. and Van Hoven, G.: Hydromagnetic Stability of Coronal Arcade Structures: the Effects of Photospheric Line Tying, Solar Phys. 79, 1982, pp. 353-364.
- Roberts, P.H.: Velocity Fields in Magnetically Disturbed Regions of the H α Chromosphere, Ph.D. Thesis, California Institute of Technology, 1970.
- Roberts, R. and Frankenthal, S.: The Thermal Statics of Coronal Loops, Solar Phys. 68, 1980, pp. 103-109.
- Rock, K., Fisher, R., Garcia, H., and Hasukawa: A Summary of Solar Activity Observed at the MLSO, NCAR/TN-221+STR, Nov. 1983, 1980-1983.
- Rosner, R., Tucker, W. and Vaiana, G.L.: The Dynamics of the Quiescent Solar Corona, Astrophys. J. 220, 1978, 643-665.
- Roy, J.R. and Tang, F.: Slow X-Ray Bursts and Flares with Filament Disruption, Solar Phys. 42, 1975, pp. 425-439.
- Roy, J.-R. and Michalitsanos, A.F.: Chromospheric Activity Associated with Moving Magnetic Fields, Solar Phys. 35, 1974, pp. 47-54.
- Rust, D.M.: Chromospheric Explosions and Satellite Sunspots. Structures and Development of Solar Active Regions, IAU Symposium 35, K.O. Kiepenheuer (ed.), D. Reidel Publishing Co., Holland, 1968, pp. 77-84.
- Rust, D.M.: Flares and Changing Magnetic Fields, Solar Phys. 25, 1972, pp. 141-157.
- Rust, D.M. and Roy, J.-R.: The Late June 1972 "CINOF" Flares, AFCRL-TR-75-0437, 1975, pp. 61-93.
- Rust, D.M. and Bridges, C.A.: The Work of the Diode Array: He 10830 Observations of Spicules and Subflares, Solar Phys. 43, 1975, pp. 129-145.
- Rust, D.M., Nakagawa, Y. and Neupert, W.M.: EUV Emission, Filament Activation and Magnetic Fields in a Slow-Rise Flare, Solar Phys. 41, 1975, pp. 397-414.
- Rust, D.M. and Hildner, E.: Expansion of an X-ray Coronal Arch into the Outer Corona, Solar Phys. 48, 1976, pp. 381-387.
- Rust, D.M.: Observations of Flare-Associated Magnetic Field Changes, Phil. Trans. R. Soc. London, Ser. A. 281, 1976, pp. 427-433.
- Rust, D. and Webb, D.F.: Soft X-Ray Observations of Large-Scale Coronal Active Region Brightenings, Solar Phys. 54, 1977, pp. 403-417.
- Rust, D.M., Benz, A.O., Hurford, G.J., Nelson, G., Pick, M., and Ruzdjak, V.: Optical and Radio Observations of the 29 March, 30 April and 7 June 1980 Flares, Astrophys. J. 244, 1981, pp. L179-L183.
- Rust, D.M., Buhmann, R.W., Dennis, B.R., Robinson, R.D., Willson, R.R., Simon, M. and the SMM XRP team: Spatial and Temporal Correlation of High and Low Temperature Solar Flare Emissions, Bull. Am. Astr. Soc. 12, 1980, p. 752.
- Rutherford, P.H.: Nonlinear Growth of the Tearing Mode, Phys. Fluids 16, 1973, pp. 1903-1908.
- Sakurai, T.: Magnetohydrodynamic Interpretation of the Motion of Prominences, Publ. Astr. Soc. Japan 28, 1976, pp. 177-198.
- Schadee, A., deJager, C. and Svestka, Z.: Enhanced X-Ray Emission Above 3.5 keV in Active Regions in the Absence of Flares, Solar Phys. 89, 1983, 287-306.
- Schadee, A. and Gaizauskas, V.: Identification of Two X-Ray Miniflares with H α Subflares, Adv. Space Res. 4, 1984, pp. 117-120 (XXV COSPAR, Graz).
- Schindler, K., Birn, J. and Janicke, L.: Stability of Two-Dimensional Preflare Structures, Solar Phys. 87, 1983, pp. 103-134.
- Schmahl, E.J.: Flare Buildup in X-rays, UV, Microwaves, and White Light, Adv. Space Res. (Eds. Svestka, Rust and Dryer) 2, 1983, pp. 73-90.
- Schmieder, B., Vial, J.C., Mein, P. and Tandberg-Hanssen, E.: Dynamics of a Surge Observed in the C IV and H α Lines, Astron. Astrophys. 127, 1983, pp. 337-344.
- Schmieder, B., Mein, P., Martres, M.-J. and Tandberg-Hanssen, E.: Dynamic Evolution of Recurrent Mass Ejection Observed in H α and C IV Lines, Solar Phys. 94, 1984, pp. 133-154.
- Schoolman, S.: Videomagnetograph Studies of Solar Magnetic Fields II: Field Changes in an Active Region, Solar Phys. 32, 1973, pp. 379-388.
- Sheeley, N.R.: The Evolution of the Photospheric Network, Solar Phys. 9, 1969, pp. 347-357.
- Sheeley, N.R., Jr., Bohlin, J.D., Brueckner, G.E., Purcell, J.D., Scherrer, V.E., Tousey, R., Smith, J.B., Jr., Speich, D.M., Tandberg-Hanssen, E., Wilson, R.M., deLoach, A.C., Hoover, R.B. and McGuire, J.P., Solar Phys. 45, 1975, pp. 377-392.
- Sheeley, N.R. and Golub, L.: Rapid Changes in the Fine Structure of a Coronal "Bright Point" and a Small Coronal "Active Region", Solar Phys. 63, 1979, pp. 119-126.
- Sheeley, N.R.: Temporal Variations of Loop Structures in the Solar Atmosphere, Solar Phys. 66, 1980, pp. 79-87.
- Sheeley, N.R.: The Overall Structure and Evolution of Active Regions. Solar Active Regions, F.Q. Orrall (ed.), Colorado Associated University Press, 1981, pp. 17-42.
- Sime, D., Fisher, R., and Munro, R.: Ground-Based Observations of the Corona Following the 29 June 1821 Flare, Bull. Am. Astr. Soc. 12, 1980, p. 903.
- Simnett, G.M. and Harrison, R.: The Relationship Between Coronal Mass Ejections and Solar Flares, Solar Phys., Advances in Space Research, COSPAR, 1984, 4, pp. 279-282.
- Simon, G., Mein, N., Mein, P. and Gesztely, L.: Preflare Activity of Solar Prominences, Solar Phys. 93, 1984, pp. 325-336.
- Smith, S.F. and Howard, R.: Magnetic Classification of Active

- Regions, Structure and Development of Solar Active Regions, IAU Symposium 35, K.O. Kiepenheuer (ed.), D. Reidel Publishing Co., Holland, 1968, pp. 33-42.
- Smith, J. B., Jr., Krall, K. R., Hagyard, M. J., Cumings, N. P., West, E., Reichmann, E., and Smith, J. E.: Vector Magnetic Measurements of an Active Region. *Bulletin Am. Astron. Soc.* 11, 1979, p. 440.
- Smith, S.F. and Ramsey, H.E.: The Flare-Associated Filament Disappearance, *Zeit. F. Phys.* 60, 1964, pp. 371-387.
- Solar Geophysical Data, World Data Center A, Solar Radio Emission, Outstanding Occurrences, 4418, 1981, pp. 5-45.
- Sonnerup, B.U.O.: Magnetic Field Reconnection in a Highly Conducting Incompressible Fluid, *J. Plasma Phys.* 4, 1970, pp. 161-174.
- Steinolfson, R.S.: Energetics and the Resistive Tearing Mode: Effects of Joule Heating and Radiation, *Phys. Fluids* 26, 1983, pp. 2590-2602.
- Steinolfson, R.S.: Thermal Ripples in a Resistive and Radiative Instability, *Astrophys. J.* 281, 1983, pp. 854-861.
- Steinolfson, R.S. and Van Hoven, G.: The Growth of the Tearing Mode; Boundary and Scaling Effects, *Phys. Fluids* 26, 1983, pp. 117-123.
- Steinolfson, R.S. and Van Hoven, G.: Radiative Tearing: Magnetic Reconnection on a Fast Thermal-Instability Time-Scale, *Astrophys. J.* 276, 1984a, pp. 391-398.
- Steinolfson, R.S. and Van Hoven, G.: Nonlinear Evolution of the Resistive Tearing Mode, *Phys. Fluids* 27, 1984b, pp. 1207-1214.
- Stewart, R.T.: Homologous Type II Radio Bursts and Coronal Transients, submitted to *Solar Physics*, 1984.
- Strong, K.T., Benz, A.O., Dennis, B.R., Leibacher, J.W., Mewe, R., Poland, A., Schrijver, H., Simnett, G.M., Smith, J.B., Jr. and Sylwester, J.: A Multi Wavelength Study of a Double Impulsive Flare, *Solar Phys.*, 90, 1984, pp. 325-344.
- Sturrock, P.: Flare Models, in *Solar Flares* (ed. P. Sturrock) Colo. Assoc. Univ. Press, Boulder, 1980, pp. 441-449.
- Sung, Mu-Tao and Cao, Tian-Jun: The Instability of a Non-Static Plasma Column, *Chin. Astron. Astrophys.* 7, 1983, pp. 159-164.
- Svestka, Z., Dennis, B.R., Pick, M., Raoult, A., Rapley, C.G., Stewart, R.T. and Woodgate, B.E.: Unusual Coronal Activity Following the Flare of 6 November 1980, *Solar Phys.* 80, 1982, pp. 143-159.
- Svestka, Z., Stewart, R.T., Hoyng, P., van Tend, W., Acton, L.W., Gabriel, A.H., Rapley, C.G., Boelee, A., Bruner E.C., de Jager, C., LaFleur, H., Nelson, G., Simnett, G.J., van Beek, H.F. and Wagner, W.: Observations of a Post-Flare Radio Burst in X-Rays, *Solar Phys.* 75, 1982, pp. 305-329.
- Svestka, Z.: *Solar Flares*, D. Reidel, Dordrecht, Holland, 1976.
- Tanaka, K. and Nakagawa, Y.: Force-Free Magnetic Fields and Flares of August 1972, *Solar Phys.* 33, 1973, pp. 187-204.
- Tandberg-Hanssen, E., Reichmann, E. and Woodgate, B.: Behavior of Transition-Region Lines During Impulsive Solar Flares *Solar Phys.* 86, 1983, pp. 159-171.
- Tang, F.: On the Origin of δ Spots, *Solar Phys.* 89, 1983, pp. 43-50.
- Tang, F., Harvey, K., Bruner, M., Kent, B. and Antonucci, E.: Bright Point Study, *Adv. Space Res.* 2, 1983, pp. 65-72.
- Taylor, J.B.V.: Relaxation of Toroidal Plasma and Generation of Reverse Magnetic Fields, *Phys. Rev. Lett.*, 33, 1974, pp. 1139-1141.
- Thomas, R.J. and Teske, R.G.: Solar Soft X-Rays and Solar Activity, *Solar Phys.* 16, 1971, pp. 431-453.
- Van Hoven, G.: The Preflare State, in *Solar Flares* (ed. P. Sturrock) Colo. Assoc. Univ. Press, Boulder, 1980, pp. 17-81.
- Van Hoven, G., Steinolfson, R.S. and Tachi, T.: Energy Dynamics in Stressed Magnetic Fields: the Filamentation and Flare Instabilities, *Astrophys. J.* 268, 1983, pp. 860-864.
- Van Tend, W. and Kuperus, M.: The Development of Coronal Electric Current Systems in Active Regions and Their Relation to Filaments and Flares, *Solar Phys.* 59, 1978, pp. 115-127.
- Vasyliunas, V.H.: Theoretical Models of Magnetic Field Line Merging, 1, *Rev. Geophys. Space Phys.* 13, 1975, pp. 303-336.
- Vorpahl, J.R.: Flares Associated with EFR's (Emerging Flux Regions), *Solar Phys.* 28, 1973, pp. 115-122.
- Vorpahl, J.A., Gibson, E.G., Landecker, P.B., McKenzie, D.L. and Underwood, J.H.: Observations of the Structure and Evolution of Solar Flares with a Soft X-Ray Telescope, *Solar Phys.* 45, 1975, pp. 199-216.
- Vrabc, D.: Streaming Magnetic Features Near Sunspots. *Chromospheric Fine Structure*, IAU Symposium 56, A.G. Athay (ed.), D. Reidel Publishing Co., Holland, 1974, pp. 201-231.
- Waddell, B.V., Carreras, B., Hicks, H.R., Holmes, R.A. and Lee D.K.: Mechanism for Major Disruption in Tokamaks, *Phys. Rev. Letts.* 41, 1978, pp. 1386-1389.
- Wagner, W.J.: SERF Studies of Mass Motions Arising in Flares, in *Advances Space Res.* (eds. Z. Svestka, D.M. Rust and M. Dryer), 2, 1982, pp. 203-219.
- Weart, S.R. and Zirin, H.: The Birth of Active Regions, *Publ. Astron. Soc. Pacific* 81, 1969, pp. 270-273.
- Weart, S.R.: The Birth and Growth of Sunspot Regions, *Astrophys. J.* 162, 1980, pp. 987-992.
- Webb, D.F., Krieger, A.S. and Rust, D.M.: Coronal X-Ray Enhancements with $H\alpha$ Filament Disappearances, *Solar Phys.* 48, 1976, pp. 159-186.
- Webb, D.F.: A Study of Coronal Precursors of Solar Flares, Technical Report AFGL-TR-83-0126, 1983.
- Webb, D.F. and Kundu, M.R.: The Association of Nonthermal Electrons with Non-Flaring Coronal Transients, *Solar Phys.* 57, 1978, pp. 155-173.
- Wiehl, H., Batchelor, D.A., Crannell, C.J., Dennis, B.R. and Price, P.N.: Great Microwave Bursts and Hard X-Rays from Solar Flares, 1983, NASA TM85052.
- Willson, R.: High Resolution Observations of Solar Radio Bursts at 2, 6 and 20 cm Wavelength, *Solar Phys.* 83, 1983, pp. 285-303.
- Willson, R. and Lang, K.R.: Very Large Array Observations of Solar Active Regions: IV Structure and Evolution of Radio Bursts from 20 cm Loops, *Astrophys. J.* 279, 1984, pp. 427-437.
- Wolfson, C.J., Doyle, J.G., Leibacher, J.W. and Phillips, K.J.H.: X-Ray Line Ratios from Helium-Like Ions: Updated Theory and SMM Flare Observations, *Astrophys. J.* 269, 1983, pp. 319-328.
- Wolfson, C.J.: Soft X-Ray Emission from Active Regions Shortly Before Solar Flares, *Solar Phys.* 76, 1982, pp. 377-386.
- Woodgate, B.E., Shine, R.A., Schmahl, E.J., Kundu, M.R., and Gaizauskas, V.: Upflows Immediately Prior to the Impulsive Phase of Solar Flares, *Bull. Am. Astr. Soc.* 14, 1982, p. 898.
- Woodgate, B.E., Shine, R.A., Brandt, J.C., Chapman, R.D., Michalitsanos, A.E., Kenny, P.J., Bruner, E.C., Rehse, R.A., Schoolman, S.A., Cheng, C.-C., Tandberg-Hanssen, E., Athay, R.G., Beckers, J.M., Gurman, J.B., Henze, W. and

- Hyder C.L.: Observations of the 1980 April 30 Limb Flare by the Ultraviolet Spectrometer and Polarimeter on the Solar Maximum Mission, *Astrophys. J. (Letters)* **244**, 1981, L133-L135.
- Woodgate, B.E.: Flare Buildup Studies - Homologous Flares Group Interim Report, *Adv. in Space Research* (eds. Z. Svestka, D. Rust and M. Dryer) **2**, 1983, pp. 61-64.
- Woodgate, B.E., Shine, R.A., Poland, A.I. and Orwig, L.E.: Simultaneous Ultraviolet Line and Hard X-Ray Bursts in the Impulsive Phase of Solar Flares, *Astrophys. J.* **265**, 1983, pp. 530-534.
- Woodgate, B.E., Martres, M.J., Smith, J.B.Jr., Strong, K.T., McCabe, M.K., Machado, M.E., Gaizauskas, V., Stewart, R.T., and Sturrock, P.A.: Progress in the Study of Homologous Flares on the Sun - Part II, *Advances in Space Research* **4**, No. 7 (1984) pp 11-17.
- Wu, S.T., Wang, S., Dryer, M., Poland, A.I., Sime, D.G., Wolfson, C.J., Orwig, L.E. and Maxwell, A.: Magnetohydrodynamic Simulation of the Coronal Transient Associated with the Solar Limb Flare of 1980, June 29, 18:21 UT, *Solar Phys.* **85**, 1983, 351-373.
- Wu, S. T., Hu, Y. Q., Krall, K. R., Hagyard, M. J., and Smith, J. B., Jr.: Modeling of Energy Buildup for a Flare-Productive Region. *Solar Phys.* **90**, 1984, pp. 117-131.
- Yang, C.K. and Sonnerup, B.U.O.: Compressible Magnetic Field Reconnection, A Slow Wave Model, *Astrophys. J.* **206**, 1976, pp. 570-582.
- Zirin, H.: Active Regions I: The Occurrence of Solar Flares and the Development of Active Regions, *Solar Phys.* **14**, 1970, 328-341.
- Zirin, H.: Fine Structure of Solar Magnetic Fields, *Solar Phys.* **22**, 1972, pp. 34-38.
- Zirin, H. and Tanaka, K.: The Flares of August 1972. *Solar Phys.* **32**, 1973, pp. 173-207.
- Zirin, H.: The Magnetic Structure of Plages. Chromospheric Fine Structure, *IAU Symposium 56*, R.G. Athay (ed.), D. Reidel Publishing Co., Holland, 1974, pp. 161-175.
- Zirin, H.: The Optical Flare, *Proc. U.S. Japan Seminar*, *Solar Phys.* **86**, 1983, pp. 173-184.
- Zirin, H.: The 1981 July 26-27 Flares: Magnetic Developments Leading to and Following Flares, *Astrophys. J.* **274**, 1983, pp. 900-909.
- Zwaan, C.: On the Appearance of Magnetic Flux in the Solar Photosphere, *Solar Phys.* **60**, 1978, pp. 213-240.
- Zwaan, C.: Solar Magnetic Structure and the Solar Activity Cycle, Review of Observational Data - The Sun as a Star, S. Jordan (ed.), NASA SP-450, 1981, pp. 163-179.
- Zwaan, C., Brants, J.J. and Cram, L.E.: High-Resolution Spectroscopy of Active Regions I: Observing Procedures. *Solar Phys.* **95**, 1985, pp. 3-14.
- Zweibel, E.: MHD Instabilities of Atmospheres with Magnetic Fields, *Astrophys. J.* **249**, 1981, pp. 731-745.
- Zweibel, E. and Hundhausen, A.: Magnetostatic Atmospheres: a Family of Isothermal Solutions, *Solar Phys.* **76**, 1982, pp. 261-299.